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ABSTRACT

The purpose of this study was to provide an overview of compression devices used to increase the cost effectiveness of teleconferences by reducing satellite bandwidth requirements for the transmission of television pictures and accompanying audio signals. The main body of the report describes the comparison study of compression rates and their effects on video quality using a common source tape of color graphics, teleconference scenes, and motion footage. The remaining sections of the report describe the equipment tested, equipment configurations, actual bench and field test results, current academic applications using compression technology, and equipment prices and features. (GL)

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A Comparative Study of Compression Video Technology

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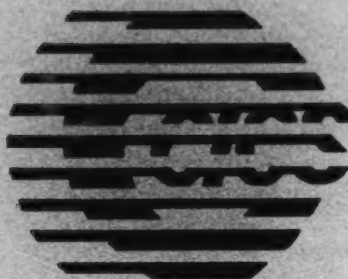
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by

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Introduction

This report reflects an increasing interest on the part of higher education in compressed video capabilities. As electronic means become increasingly available and attractive for campuses to enhance their internal communications as well as to meet their outreach commitments, such technologies as compressed video become natural targets for exploration.

Founded in 1982, the National University Teleconference Network (NUTN) has offered ever-larger numbers of satellite-delivered teleconferences to the higher education community. Having grown to be a consortium of some 260 member institutions, NUTN has become keenly interested in exploring alternatives to the fairly expensive (and soon to be more expensive) method of providing teleconferences via full-transponder satellite delivery.

The recent improvements in compressed video, coupled with falling prices, have encouraged NUTN, through its Technical Resource Group, to undertake a study of compression products. The Applied Research Institute, an agency of the Center for Information and Communication Sciences at Ball State University, was engaged to conduct the study, and the enclosed report is the result.

Briefly, compressed video is a means by which the vast amount of information contained in a television picture (and accompanying audio signal) is squeezed onto a smaller carrier. The result is that much of the information is sacrificed in transmission, and with a significant amount of "squeezing," the viewer will begin to notice that the color is not as good, or the picture is less clear, or motion becomes less smooth.

Given these disadvantages, why compress the video at all? Not surprisingly, the answer is an economic one: the amount of "bandwidth" required to carry a full television signal is expensive. To send teleconferences over land lines (combined telephone lines) has traditionally been

prohibitively costly for higher education. Fortunately for users, satellite bandwidth has been available at much more favorable rates, but experts warn that those rates will soon begin to climb. However, compressing the video signal and paying for only a fraction of the full bandwidth can result in significant savings. And many television applications in higher education can utilize the compressed signals with no loss of learning or communication. The educational network of one major corporation has successfully used compression for some time to place as many as 24 separate televised classes onto a single satellite channel, with considerable savings!

Observations to be Drawn from this Study

Hundreds of hours were spent in designing the study; arranging with leading manufacturers to consign their products for testing; coordinating shipping schedules; receiving and installing the equipment; preparing a common source tape of still (graphic) images, teleconference scenes, and motion footage; performing the bench tests; recruiting subjects and conducting the field tests; video taping the resulting imagery; analyzing the results and finally, preparing this summary and the full report. Predictably, some products showed strengths in certain fea-

tures, whereas others were judged more suitable for different applications. We found that quality tended to rise in rough correlation with higher prices, as one might expect.

The following observations may be drawn:

1. Compression technologies have come a long way since the early days. Signals have been increasingly compressed, and equipment costs have dropped, while picture quality has remained relatively good. A "watchable" picture can be delivered at 384 Kbps, which is only 0.42 % of the original information in the signal. This is a compression ratio of 234 to 1.

Some companies have dropped the ratio another three-fold, and have products which can furnish a reasonable color video teleconferencing signal using two 56 or 64 kilobit/second telephone lines! When ISDN (Integrated Services Digital Network) service becomes widely available in the 1990s, these video conference units (or the next generation) will come into common use in many offices, and may play a role in distance education.

2. Compression devices no longer merely digitize, encode, and decode video signals. One may now purchase units which will blend in ("multiplex") data signals which can be sent with the video, so graphics or other types of information may be sent simultaneously. Sophisticated software controls allow remote operation of the "codecs," as the compression devices are termed, and in some models permit inexpensive upgrading of the codec when new developments become available. Software also allows "multi-way" meetings in which several sites can interact and see each other. If privacy is needed, some systems permit the signals to be "encrypted" for security. An option on many models allows remote control of the equipment from any point in the network. Also, most codecs are not fixed on one data rate but have a range of compression (e.g., 56 to 384Kbps or 768Kbps to 1.544Mbps), and a few even allow the user to infinitely select the compression rate within the allowable range. Some machines are capable of detecting the network rate and adjusting to it automatically.

3. Despite continuing decline in the cost of compression hardware and software, they still represent an expensive

investment. Codecs reviewed for this study ranged from a low of \$29,950 to \$73,000 (list prices). And the user must keep in mind that two codecs are needed, one at each end of the channel. Then there are likely additional costs: PC controllers, high quality monitors, multiplexers, data ports, RGB graphics interfaces, and video switchers. Most vendors will provide a full videoconferencing room system, at extra cost of course. Therefore, unless truly significant savings in transmission (bandwidth) costs can be anticipated, the purchase of codecs and attendant equipment is often contra-indicated. However, vendors typically have educational discounts of ten to twenty per cent, and other options include renting equipment or leasing to own.

4. Standards, a major consideration in evaluating electronic communication systems, are emerging in respect to video compression. Recognizing that the codec market will remain hobbled until working standards are in place, engineers from leading companies are cooperating to produce a provisional "Px64" standard under the CCITT (Consultative Committee of the International Telephone and Telegraph group) by mid-1990. Some

vendors are already planning to adhere to that standard, but it will undoubtedly be some time before one manufacturer's box can talk to another's. Meanwhile, most, if not all, products from the same manufacturer can be used compatibly with each other.

5. Obviously, some link must exist between the codecs. This may be a physical connection, such as telephone lines, coax cable, or fiber optics, or it may be a "through-the-air" transmission, as by terrestrial microwave or even a satellite link-up. Only fairly recently have a number of alternatives become available to use a public switched network (such as AT&T or other carrier) to carry compressed video. Even more recently, multiple vendors have begun to provide "fractional T1" equipment or services; these services are necessary to realize the full cost-saving potential of video compression (as well as voice and data compression). Although the cost of acquiring such equipment or services is also quite high at this time, there are doubtless circumstances under which it will still be cost-effective to buy or lease them.

The new owner of most makes of compression equipment will be bewildered by the array of interconnections which can be made from the "boxes." One can connect to T1, G703/732, RS-422/449, V.11, and V.35 networks, to name a few. In some cases, the buyer must specify the interface when ordering the equipment. In all cases, our experience shows, it is critical to work closely with the vendor to obtain precisely the cables, pin-out schemes, etc., which will allow the customer to make the needed connections.

Implications for Higher Education

While codec technology and the evolution of standards has come a long way, it is not quite yet a "mature" capability. However, a growing number of colleges and universities have invested in video compression (the full report lists fifteen current users and 16 schools awaiting transmission connections), and there are situations in which an institution would be justified in considering the acquisition of codecs. Some of these are:

-- An application in which images must be delivered between two or more sites over leased channels (for example, public switched network lines). Leased bandwidth

can be enormously expensive when billed month after month.

-- A campus communications plan which must accommodate significantly high levels of voice and/or data traffic. In such situations, codecs may already be anticipated, and the addition of codecs for video may not be unreasonably costly.

-- A situation involving large volumes of video traffic day after day.

-- A situation in which the institution is faced with putting in new video channels to accommodate a surge of use. For instance, existing microwave channels between two campuses might become over-scheduled, and additional transmitters might be more expensive than compression equipment. In some situations, the necessary additional microwave licenses might be unavailable.

Will video compression soon replace full-bandwidth transmission of NUTN teleconferences? For that to occur would require that virtually all subscribing institutions have compatible receiving codecs and be networked together either by satellite or by land lines. This scenario

will certainly not occur before the Px64 standard is widely implemented, and the economics of acquiring codecs will probably remain prohibitive for many institutions at least well into the 1990s. However, as the "installed base" of codecs grows among colleges and universities, the possibility for linking campuses via compression will become increasingly attractive and cost-effective.

Caveats for Institutions

Purchasers should look carefully at competing systems to ensure that the system answers to their specific needs and applications. As the report notes, the particular algorithm used by one system may favor color fidelity over motion, while another's may enjoy better resolution. An engineering application using computer graphics, for example, may require high resolution, but may be indifferent as to motion.

Another consideration is whether additional features might be needed. Some vendors offer data, multi-way, remote control, encryption or mobile site capabilities which may be added to the package.

For most applications, it will be critical that the system purchased have the capability of conforming to the Px64 standard and also taking advantage of any upgrades which may become available. Although no manufacturer can warrant today that its products will unerringly meet the new standards, some seem to have an edge. Those systems which are software driven will probably be able to provide these advantages. Needless to say, the purchaser should know exactly how the video codecs will be integrated into the total communications plan of the institution.

The usual caveats apply in regard to warranties, delivery schedules, responsibility for installation, and the like. Of particular concern if the equipment is to interface with a network not controlled by the institution is that of maintenance and servicing; the potential for "finger-pointing" among providers is particularly high in this relatively untested application.

Summary

In sum, video compression technologies have made astonishing progress in this decade, in terms of both quality and cost. However, the point at which quality has climbed and costs have dropped sufficiently to allow widespread use in higher education is still a ways off. Fortunately, continued progress appears to be assured on both fronts, and in the meantime, video compression is already finding its niche in specialized applications at several institutions.

The optimal benefit of any investment in compressed video, now or at any future time, will result from the thoughtful integration of this technology into an institution's master communications plan. Cost-effectiveness can be enhanced by careful matching of the technology, including any special features which might be required, to the need. Attention to upgrades, including those which are designed to embrace the emerging standards, seems destined to yield additional benefits.

Compression video is an exciting concept whose time is coming. As with most technologies, it is still expensive. Used appropriately, it can be cost-effective. Used unwisely, it can be a costly mistake. The next few years will be pivotal in determining how much and how well video compression will contribute to higher education.

The following report was prepared by Chris Keller and Mike Staab under my direction. I trust it will be useful to you, and I would be delighted to hear your comments and evaluation of this effort.

Richard A. Stowe, Ed.D.

Project Coordinator

Assistant Director

Center for Information and Communication Sciences

Chair, Technical Resource Group

National University Teleconferencing Network

Purpose of the Study

When we initially began this project earlier this year we wanted to do a full-blown comparison of video compression units ranging from 56 Kbps to 45 Mbps. As our study progressed we realized that the comparative segment of our study would play a smaller, but equally important role, in a much larger look at compression technology and the options available to users today. While the report does contain bench and field tests at varying rates, we enlarged the perspective to give the reader an introduction to compression video technology and what we discovered during our experience. Included in the report is a primer with the basics on compressed video for those who are new to the technology.

The primary purpose of our study was not to determine the best codec in the market, but to provide a view of the technology and major players. Included in this discussion is a comparison of compression rates, the effect of compression rates on three different video settings (Color Graphics, Teleconference, Motion), and a report of what types of applications are currently being utilized by institu-

tions today. While our subjective test played a less important role than initially expected, its importance should not be diminished. The results of the tests give good quantitative data for across-the-board comparison of the units tested.

The remaining sections of the report will cover the equipment tested, equipment configurations, actual bench and field test results, current academic applications using compression technology, equipment prices, features and concluding comments.

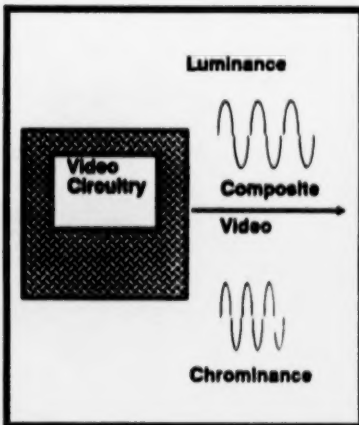
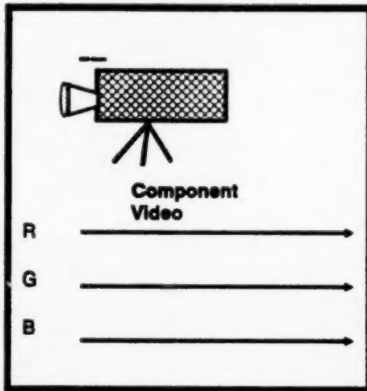
While these elements are important to consider, our study was predominantly centered around the video quality of each codec at different compression rates. After completing our study we would be the first ones to admit that video quality is just one of the many factors to consider. While comparison testing was based upon video quality, a variety of different options from rack mounted units to complete systems exist depending on the users needs and environment. Additional functions such as data and graphics ports, out of band audio, encryption and audio delays offer the user a multitude of options to consider when choosing a particular system.

Complete compression systems provide users with the ability to adapt video conferencing to many industry en-

vironments. In the past the teleconferencing medium was restricted to a high-tech broadcast studio suited mainly for the use of top management.

In discussion with users and vendors alike, it appears that the marketplace is moving toward systems that break down the barriers of the technology allowing for the greatest amount of flexibility and user interactivity - a complete turnkey system.

Compressed Video Primer



Codecs

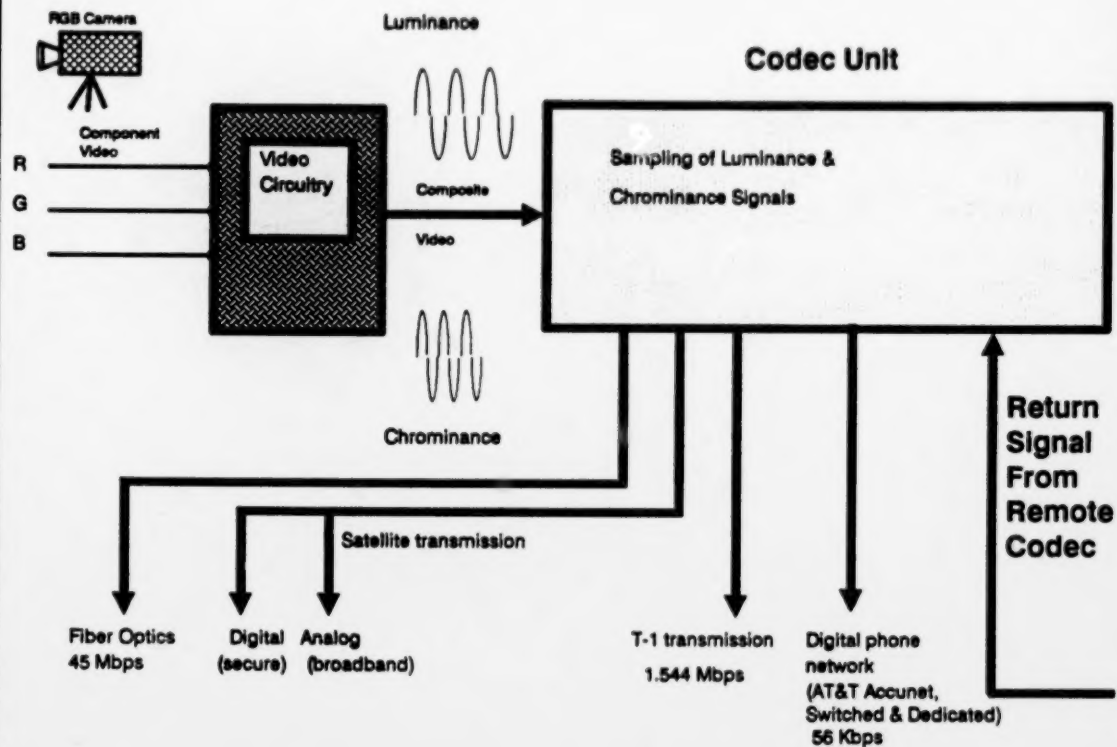
A COder/DECoder(codec) is defined as equipment, hardware, and software which changes an analog signal into a compressed digital signal at varying rates for transmission over digital networks while simultaneously performing the reverse process from the distant codec.

An analog television signal, under NTSC standards, with full motion color uses a bandwidth of about 4 Mhz. With spacing between stations the total bandwidth comprises 6 Mhz.

When converted digitally, the signal equates to a 96 Mbps data rate.

Compression Process

Converting a television signal to a compressed digital format is a multi-step process. First, since the signal from the camera is traditionally RGB (red, green, blue), the signal is converted to a composite signal, with luminance (brightness) and chrominance (color) components. Since



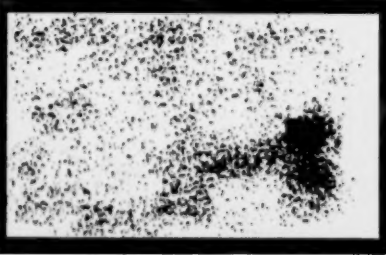
Video Compression: Coder/Decoder

the luminance component contains a larger amount of information, it is coded more accurately than the chrominance components. These signals are still in an analog format. Pulse Code Modulation (PCM) and Adaptive Differential Pulse Code Modulation (ADCPM) are the two main methods used to convert these analog signals into digital signals. In the codec, this information is defined in terms of a matrix array of the actual frame.

Here, the compression of the signal begins. A choice is generally made between interframe and intraframe coding for the compression of the signal.

Interframe Compression

Interframe encoding compares one frame to the next and sends only pixel element changes. Pixels are small picture elements that comprise the total frame (picture). In interframe encoding the codec only transmits those pixels that change from one frame to the next. Then every two seconds the entire frame is refreshed.



Interframe Coding

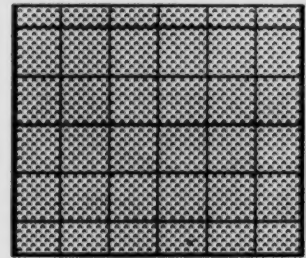
Intraframe Compression

With intraframe compression, the frame is divided into sectors, with each sector having 16 x 16 pixels. An algorithm is used to scan each sector of the frame to determine whether or not a specific sector, or block, has changed since the last scan. If any pixels have changed in that block, the block is retransmitted.

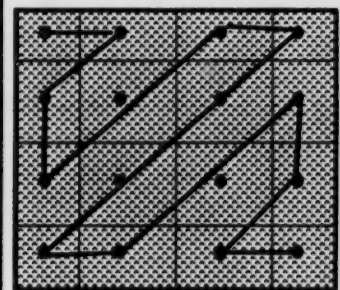
Sub-Block Scanning

To facilitate a smooth updating of "blocks", three sub-block scanning methods are used: Zig-Zag scanning, vertical scanning, and horizontal scanning. Each of these methods are used sequentially to determine which adjacent blocks change frequently. In this manner, the most efficient scanning method can be implemented to speed up the transmission process. The goal is to quickly update portions of the frame in which movement occurs.

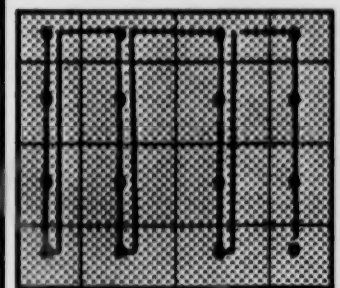
A third and more recent innovation in encoding is Hierarchical Vector Quantization (HVQ). Developed by Picture-Tel, the compression algorithm is housed in the software



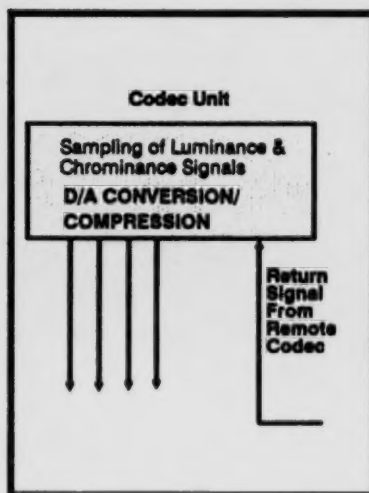
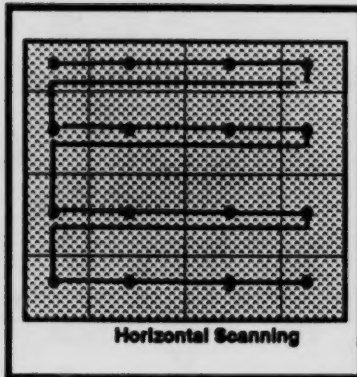
Intraframe Coding



Zig-Zag Scanning



Vertical Scanning



unlike previous methods that were hardware based. This technology is not totally different from interframe and intraframe encoding but combines the two in a more effective manner.

Hardware/Software Based Codecs

Codecs can be divided into two major types: hardware and software based. With a hardware-based system, the compression technique is a function of the hardware and tends not to be easily upgradable. In the software-based system, a codec's hardware is developed independently of its compression algorithms thus allowing for varying rates of compression by simply changing the software. Using software-based systems also gives more flexible in adapting to older machines that might have limited capabilities.

Transmission Media

Currently codecs transmit data from 1.2 Kbps to 45 Mbps on dial-up, leased, or owned networks. These could include digital telephone lines, microwave, satellite, VSAT, and T-1. In the industry there are three different levels of compression. The first is on the low end, from 56 Kbps -

384 Kbps. The next range stretches from 768 Kbps - 1.5 Mbps. And finally on the higher end we see 2:1 compression at 45 Mbps.

Of course, the more we compress the signal the less expensive the transmission but the lower the quality. For example, over a 56 Kbps line the signal is refreshed only about every 15 seconds. Signals compressed at this rate tend to result in the "waterfall" effect with the picture gradually filling the screen. However, this can be eliminated, at increased expense of course, by using a frame storage unit to accept the frame and relay it to the monitor after the entire frame has been received.

Bandwidth

Most compressed video conferencing falls into the range between 56 Kbps and 2.048 Mbps. These data speeds are well over the maximum baud rate for a standard telephone line. However, a normal voice grade telephone line can handle "freeze-frame" or still-image video. An example of this type of freeze-frame technology would be the black and white picture phones available to consumers for a few hundred dollars. In the past, typical users on the low end were organizations that communicated on a daily basis

Transmission Media

Satellite C, KU

**Analog Broadband
& Digital Secure
encrypted**

T-1 1.544 Mbps

**Digital Phone
e.g. AT&T Accunet
56**

**Switched & Dedi-
cated 56 Kbps**

VSAT

between dispersed parties in such areas as engineering, sales and manufacturing groups.

Standards

In 1984 the CCITT made an initial attempt to introduce a standard for international video compression. It was called COST 211 and it mandated a fixed bandwidth of 2.048 Mbps. As technology grew more efficient this standard became inefficient. As usual, the world became divided over a set standard and the marketplace split, with Europe following COST 211 and the U.S. and Japan pursuing alternate courses.

CCITT has proposed a standard to replace COST 211 called N x 384 Kbps. This would apply to codecs operating at rates of 384 Kbps to 2.048 Mbps. It was soon recognized that a second standard would be needed on the lower end. So this led to M x 64 Kbps for codecs operating between 64 Kbps to 128 Kbps.

In 1988 CCITT proposed a new standard P x 64 Kbps that will allow codecs to transmit in multiples of 64 Kbps up to 2.048 Mbps. (This would include low to high end ISDN)

The adoption of this universal standard would enable all types of equipment to communicate directly through use of a common algorithm.

A Basic Guide to Compressed Video Features

This section was designed to provide the user with an outline of the fundamentals necessary to compare codec systems. In this section, we will discuss basic terminology relative to the hardware of the systems and a description of features common to many systems.

Out-of-Band Audio

A video compression system provides capabilities of transmitting video and audio signals in compressed form through a transmission network. However, there may be times when it is desirable to move the audio through another medium, such as the public or private telephone network. This would allow the user to add other participants to a video conference with audio only. Bringing in an "expert" for a short period of time via audio or allowing other sites without video facilities to listen in to important discussions are all excellent reasons for considering out-of-band audio.

Generally, the out-of-band audio systems provide a modular RJ-11 jack to which the phone network may be

connected. By combining this through a conference call which may be controlled through a PBX or with a "bridge" by one of the long distance carriers, other audio sites are easily added. A public "bridge" may operate in one of two fashions. The call may be set up by the originating site, dialing each new participant individually, or a special bridge will allow new calls to be dialed directly into the conference. These types of features are dependent upon vendor and should be investigated for details about these options.

Audio Delay

While audio may be in-band or out-of-band, the slower transmission rates for video demand that the audio signals be "delayed" so that the video transmission has time to catch up to the audio. Without this feature, the audio portion will be heard almost instantaneously while the video will still be showing lip movement and gestures. The goal is to synchronize video and audio transmissions.

Transmission Interfaces

This particular aspect of choosing a codec requires careful attention. Each vendor chooses an interface or variety of interfaces for a line of products. Most of the interfaces are

standard; however the user may encounter some variations with a particular interface when preparing to connect to a given data network. It is helpful to obtain a list of "pinouts" for each interface to compare with what is available on your network. An engineer who operates the particular network can provide assistance in comparing each vendor's interface with what is available in the current network interface.

While the interface gives one information about connecting the codec to the network, it is important to inquire about the physical and the electrical interface. For example, the RS-449 standard used by many vendors implies a 37-pin connector with an RS-422 electrical standard. Some codecs provide a male interface, others a female interface. Critical hours or days can be lost in overcoming a "simple" cable or connector mismatch. The following interfaces are the predominant interfaces users will encounter when hooking up the respective video, audio and controller components:

V.35, RS-449/RS-422, V.11, [T-1], RS-232C

DIN, B3ZS, and RCA connectors.

Clocking

Another issue to consider is the way in which the clocking is determined for compression. Is it incremental in multiples of 56, 64 or both? Some codecs allow you to enter in the exact transmission rate to the exact bit per second for added flexibility.

The 56 increments are important in that they work well with today's common carrier digital facilities, including AT&T Accunet 56. On the other hand, the 64 Kilobit increments are important as they are prepared for the introduction of ISDN.

Another important consideration is the control of the timing in the network. Some vendors will automatically take the timing from the network clock. If the timing is not found, the codec will provide a master - slave timing with one codec providing timing across the network to the "receiving" codec.

Remote Controlled Terminals

Many of the vendors in our evaluations provided an RS-232 interface for an ASCII terminal interface. With the interface, complete control of the codec could be achieved

very easily. In such cases, a modem may be placed at the remote codec to allow both units to be controlled from a central location.

Loop-back

While the codec will send and receive compressed video and audio through a transmission media, it is helpful to loop one codec back on itself, that is, compress a video and audio signal from a camera and, instead of transmitting through the network, feed that signal to the receiving circuits in the codec to view what the actual transmission will look like on the other end. In our experience, this was invaluable in isolating problems in the system. In addition, some vendors provide software control of this feature, while others require the user to remove the network connection and plug an adapter into the network interface.

NTSC / PAL: Overseas Transmission

The NTSC, or National Television Standards Committee of the United States, has provided the standards for television transmission in the United States and Japan. Using NTSC in these countries enables the use of additional equipment from cameras to monitors with no dif-

ficulty. In addition to NTSC, many codec vendors also provide PAL, a major standard in Europe and the Far East, to enable the user to work with overseas transmissions with the same equipment, providing of course that the equipment is from the same vendor.

Data Transmission

In addition to transmitting video and audio signals, codecs have the capability to transmit data via RS-232 ports from a personal computer. This will enable the user to transmit data files during a presentation at rates from 300 to 19,200 bps. This transmission, of course, will use some of the bandwidth normally used for compressing video which may degrade the video transmission quality, although the degradation should be minimal depending upon the rates selected.

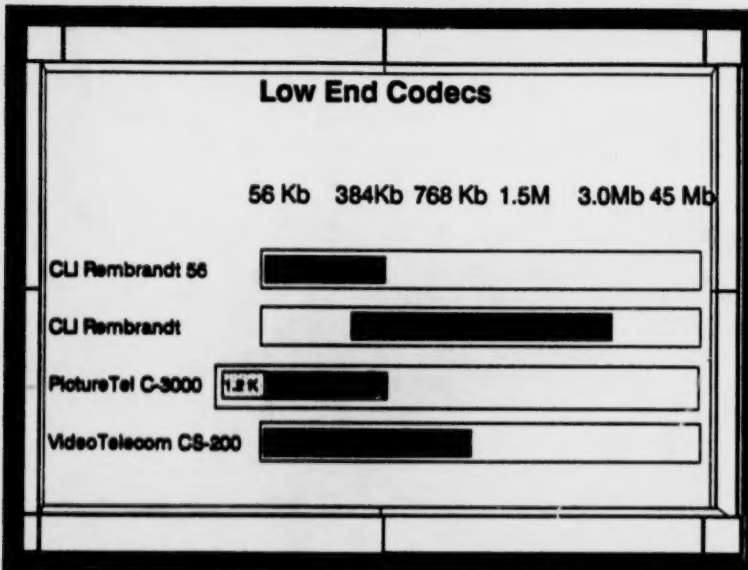
Research Design

Focus

This study focused on video compression units which transmit from 1.2 Kbps to 45 Mbps. The codecs ranged from desktop systems, designed for portability and functionality, to rack mounted communications gear designed to be located with communications network equipment. The study was designed in two phases: subjective and bench testing. The subjective test examines humans' perceptions of video quality, while the bench test is a quantative analysis of the compression video technologies.

The codecs were divided into two groups, low end compression and high end compression. The low end compression includes units ranging from 1.2 Kbps to 384 Kbps. The high end codecs range from 768 Kbps to 45 Mbps.

The study examined four low-end codecs. The following table shows each unit and its range of compression.



The Compression Lab' (CLI) Rembrandt 56 is a stand-alone codec designed for transmission rates between 56 Kbps and 384 Kbps. It provides video input and output interfaces through composite or component (RGB) video using BNC connectors.

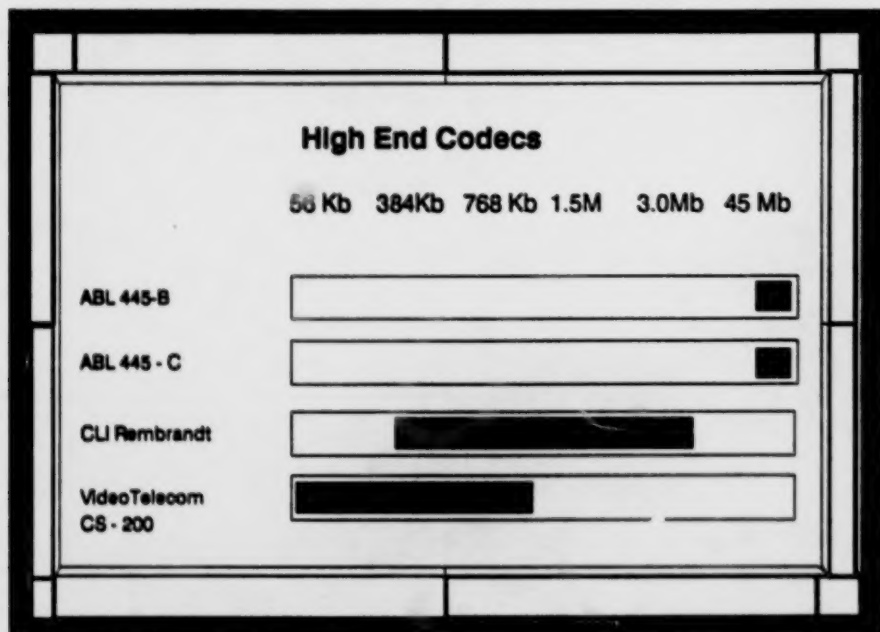
CLI's Rembrandt is a self-contained unit providing service ranging from 384 Kbps to 3.1 Mbps in increments of 64 Kbps. It is similar in design to the Rembrandt 56, however it provides BNC video input and output in RGB formats. It transmits and receives through one of five different communications interfaces: T1, NTT T1, G732, RS-449, and V.11.

The PictureTel C-3000 is a rack mounted / desktop software controlled system with transmission rates ranging from 1.2 Kbps to 384 Kbps. It utilizes a special

software cartridge which provides opportunities for future upgrades as the technology expands.

The VideoTelecom CS-200 comes as a complete turnkey, full-motion remote video conference system. The package includes full-motion compression at user-selectable speeds from 56 to 768 Kbps and full-duplex audio with automatic echo cancellation. However, for comparability, our test involved only the basic codec.

The study also examined four high-end codecs. Two of these, as the following figure shows, are units which were also tested for their low-end capabilities.



The ABL 445B is a broadcast quality 45 Mbps codec designed for rack mounting with a communications system. The 445C is the commercial counterpart to the broadcast unit. Each unit provides direct DS3 access for network interfacing and requires an external power supply of 48 volts dc.

Later in this report are detailed product descriptions and prices for each unit along with current applications in colleges and universities around the country.

Subjective Testing

The purpose of the subjective testing was twofold:

1. Evaluate the quality of video for the different vendors at different rates of compression,
2. See how the various compression rates affected the three different viewing environments outlined below.

Three different video program sources consisting of still store color graphics, a teleconference, and a section of a basketball game were selected and placed on a master tape. The segments were picked in an effort to represent quite different applications which might be required by users of compression technology.

Another goal was to determine the level of video quality compared to the "real time" equivalency and what rates viewers would be willing to tolerate for a given application.

First, the color graphics segment consisted of changing computer generated graphics in a variety of text sizes, shapes and colors to test how compression affected all of those attributes when the graphic was refreshed or changed every 5-10 seconds. (One important thing to note is that while we did utilize the color graphics segment through full-motion video, most of the units have separate graphics ports that produce a still-image with higher resolution and quality.) Secondly, the teleconference segment showed actual footage of a teleconference. And lastly the basketball segment was utilized to see how the compression affected continual motion and at what rate it became acceptable.

In an attempt to reduce as many variables as possible, our three video segments were recorded on a Super-VHS master tape that was used throughout the evaluation process. Unavoidably, the taping introduced some degradation of the signal. During our low-end test we configured our system in such a way that each set of codecs was linked through an "actual" T-1 network. Timeplex and

TelTone furnished us with multiplexers to utilize in the testing. The multiplexers allowed us to provide a simulated test environment and easily adjust transmission rates. After establishing the link between the two codecs in our network, we then input the source tape on one end and recorded the output on another S-VHS tape deck. Using an identical source tape allowed for an equitable evaluation over the different units.

Our side-by-side testing consisted of setting up four identical NEC monitors side-by-side labeled A-B-C-D. In the test at 56 Kbps we compared the three vendors (PictureTel, VideoTelecom and Rembrandt 56) side-by-side along with the real time video included in the testing segment. The purpose of including the real time video was so the subjects could rank not only the compressed video, but also the original video itself. Establishing a mark for the perceived quality of the real time video gave us a standard with which to compare the compressed video. Thirty-five subjects were recruited to participate in the test and were a non-randomly selected sample. They were primarily graduate students and faculty and most were not technically trained in television.

At 384 Kbps the source tapes for VideoTelecom, Rembrandt, Rembrandt 56 and PictureTel ran side-by-

side in the same testing environment. However, the real time video source was not included in this segment.

Our evaluation sheets were set up on a Likert Scale of seven with seven being the high score and one being the low score. For each video segment (color graphics, teleconference, and basketball), the subjects ranked each monitor (representing one vendor) according to criteria established on the sheet. The subjects were also asked to respond, in their own words, to their willingness to view the video at a particular transmission rate. Prior to testing, the subjects were told only that they were evaluating different compressed video sources and were unaware of the unit and rate of compression being shown. Appendix A shows the compiled statistics for each unit at 56 Kbps and 384 Kbps for the 35 subjects. Due to the limited number of units at rates higher than 384, we limited our subjective comparison testing to the two rates (56 and 384 Kbps).

Statistical Analysis

In order to effectively study the data from the subjective test, the scores were analyzed through the statistical package SPSS-X. We looked at a number of descriptive statistics besides mean including mode, median, standard

deviation, variance, range, frequency distribution and standard error. While the mean tends to be most susceptible to high and low scores, we felt it was the best measure of how each criterion of each segment was evaluated. Thus, it was the statistic measure displayed in Appendix A.

A repeated measures ANOVA test was also carried out to see if a significant differences existed between the subjects' scores in each criterion. Because the same 35 subjects were utilized throughout all of the test segments, we can analyze the variance in the scores between units.

In most cases, the ANOVA results exceeded the .05 level of significance. In all the segments from 56 Kbps -384 Kbps, P ranged from $< .000$ to $< .025$ with the majority being $< .000$. At 56 Kbps the real time video score was eliminated so as just to evaluate the difference among the three units.

Test Results - Low End

After evaluating the units in the range of 56 - 384 Kbps some general, but cautious, conclusions can be drawn. At 56 Kbps most people found the color graphics satisfactory,

but said they would not watch either the teleconference or basketball game at that rate. Participants cited lack of definition and sharpness in smaller text and graphics as one of the biggest problems at 56 Kbps. As for basketball, the obvious lack of smoothness of motion was noted as the major weakness.

At 384 Kbps, while the quality had obviously improved, most people still said they would not watch either the teleconference or the basketball game. The subjects said they could watch the teleconference for awhile, but that it was unacceptable for any long period of time. While the subjects found the teleconference at 384 Kbps to be somewhat acceptable, we can't say that all people would not watch a teleconference at 384 Kbps or 56 Kbps for that matter. Subjects cited contrast of color (color quality) and sharpness/clarity as the two most important factors to consider in this particular viewing environment. But of course, evaluative criteria are all dependent on the individual viewer and the application.

Conclusions at 56 Kbps

After evaluating the test results at 56 Kbps, the following conclusions surfaced. When considering all categories on the evaluation sheet, the Rembrandt 56 finished first over-

all with PictureTel next and finally VideoTelecom. The exception to this came in the color graphics segment in which VideoTelecom was ranked second to the Rembrandt 56. The subjects felt that the Rembrandt 56 and VideoTelecom units seemed to do best with color reproduction and graphics while the PictureTel did better in the teleconference and basketball segments. In Appendix A, column A shows the averages of the real time video so it can be seen how the subjects scored the original video. When the averages of the three units are compared to the real time video, there is not a great difference between the three.

Conclusions at 384 Kbps

At 384 Kbps the subjects consistently ranked the units in the order of Rembrandt (highest), Rembrandt 56, PictureTel and VideoTelecom (lowest). Except for smoothness of motion in the basketball segment, the vendors finished a solid 1, 2, 3, 4 throughout the three segments in all categories. While all units improved at the higher rate, PictureTel appeared to have the biggest improvement from 56 to 384 Kbps. While some units did perform 1 to 1.5 points higher than their counterparts, one must consider the cost to quality ratio when comparing the different units. All of these competing vendors have sys-

terms that contain similar features, but some units cost less. Cost will continue to be a factor in judging video quality.

Conclusion

As stated earlier in the report, it is difficult to determine at what level of compression a particular audience will be willing to watch a particular type of video. The majority of the subjects found the teleconference and basketball segments totally unacceptable at 56 Kbps. However, this raises the issue of whether or not the participants rated the picture on its entertainment value or on its information content. Too often video consumers in a business or educational environment place too much emphasis on the actual video image itself, instead of the content contained in the video signal. The importance of video quality in relation to the communication process is not to be understated, but in some instances the information content takes precedence over a superior video image. We must consider the environment in which the units will be utilized, understanding that each situation has specific needs (i.e. video quality, particular functions) which cannot be met by every product studied.

Practical Application

Video compression through a codec is becoming a viable technical alternative to full motion video teleconferencing for many applications, offering reduced transmission costs and increased security of transmissions through encryption and compression. Compressed video is being incorporated in education as well as in the corporate context. The future for video compression will be determined by one of two factors: either the ability of the market place to provide inexpensive compression technologies or the availability of low-cost bandwidth for transmission. As the market reaches a critical mass, prices for the technology will continue to become more affordable for consumers. On the other hand, if the cost and supply of bandwidth is low and abundant enough, then most of the market will stay with full-motion video. The increasing availability of bandwidth due to installation of extensive fiber optic networks has continued to have an effect on the industry. Also the availability of fractional T-1 service provides consumers with the option of purchasing smaller bandwidth segments than previously offered.

Generally, codecs can be used in a variety of media for transmission including fiber optics, twisted pair technologies utilizing T-1, and digital satellite transmissions. These transmissions may occur on either private networks, or in the public networks provided through a multitude of common carriers.

Currently, most codecs provide point-to-point communications capabilities. The increased availability of fractional T-1 lines will allow the users to purchase segments of the T-1 lines at a much lower cost. At this time, most users are restricted to either 56 Kbps switched or dedicated facilities or full T-1 service.

Some codecs have the option of multi-point communications. In all cases, however, it is possible to interface many locations with two-way audio through the use of an audio bridge provided through long distance carriers. An example of this is the AT&T Alliance Bridge, allowing multiple dial-up from several locations. Most codecs also provide multiple functions allowing for video, data, and high resolution graphics transmissions. In many cases, the vendor will provide one BNC connector for a video camera, one for graphics, and a variety of interfaces for data transmission which allow users to transmit additional information through the same medium. Another option

is out-of-band audio provided directly through modular RJ-11 telephone jacks. This provides greater access through audio conferencing and any other voice communication lines which may already be in place with PBX installations. Each vendor provides interfaces which allow access to the communication network for transmission. The most common interfaces which were encountered in this study were V.35 and RS-449/422. Generally, the V.35 interface is used for lower transmission rates while the RS-449/422 is more suitable for higher transmission rates.

When considering the feasibility of implementing compression video, it is important to carefully evaluate the context of the communication; (i.e. executive teleconferencing, product announcements, daily meetings of personnel at multiple locations, or occasional transmissions of graphic information used for presentations); quality of transmission desired; cost; and ease of use. These are all significant elements to consider in the development of a system for video transmission needs.

There are different types of codec units on the market. Three worth considering are rack mounted, stand-alone, and desktop personal systems. The rack mounted systems may be either self-contained or dependent upon power supplies from other communications systems equipment. The stand-alone units are fully self-contained requiring only cabling to the network(s) for the video, audio, and terminal controller connections. The desktop units, which we did not evaluate, are fully equipped with camera and microphone equipment needing only transmission medium connections. As stated earlier, careful consideration should be given to selection of a system taking into account the specific application/environment and other such factors as mobility and future compatibility.

Objective Testing

Bench Test

Video compression is achieved by sacrificing some of the color, motion, or resolution information contained in the original video signal. Each codec will solve the problem somewhat differently so that one codec may be superior to others in color, but inferior in motion or resolution. This underscores the importance of matching the codec with the user's primary needs.

Bench tests, using electronic measuring instruments, establish an objective base for comparing quality of color (through a vectorscope test) and resolution (through a multi-burst test). Unfortunately, no satisfactory test was available for the motion component.

Each unit was bench tested for video quality on the NTSC (National Television Standards Committee) standard. These tests were conducted with a Tektronix VM700 vectorscope / waveform analyzer and a Tektronix TSG-100 NTSC signal generator.

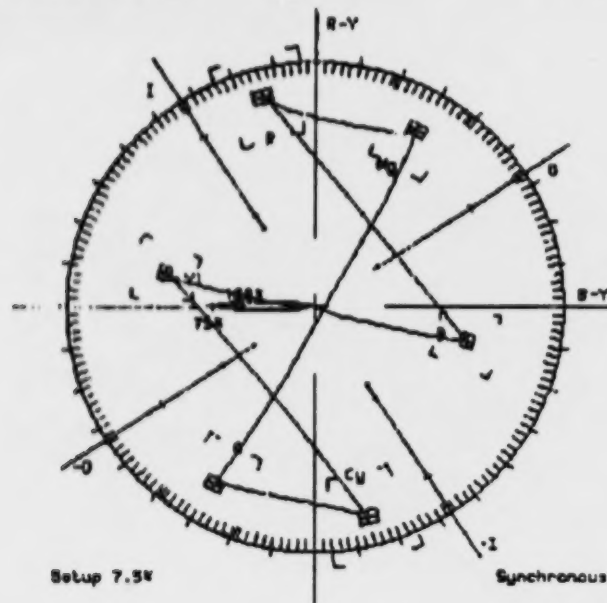
From this, we focused on two factors: color bar reproduction and relative resolution of each codec as compared with "benchmarks" produced from a non-compressed (source) signal. An example of a vectorscope waveform of the NTSC standard color bars is found on the page 50. Six small boxes represent the optimal position of the waveform for each of six colors: red, green, blue, yellow, cyan and magenta. As each waveform moves around the circle, its color changes slightly. As it moves toward the center of the circle, the intensity of the color decreases.

The second aspect, resolution, is tested with a multi-burst test. The multi-burst test displays an X-Y graph with sawtooth waveforms depicting the vertical lines of resolution progressing from left to right. Most of the units begin to decrease in amplitude significantly after the third set of lines. Fig. 2 depicts a standard display for multi-burst (resolution) tests.

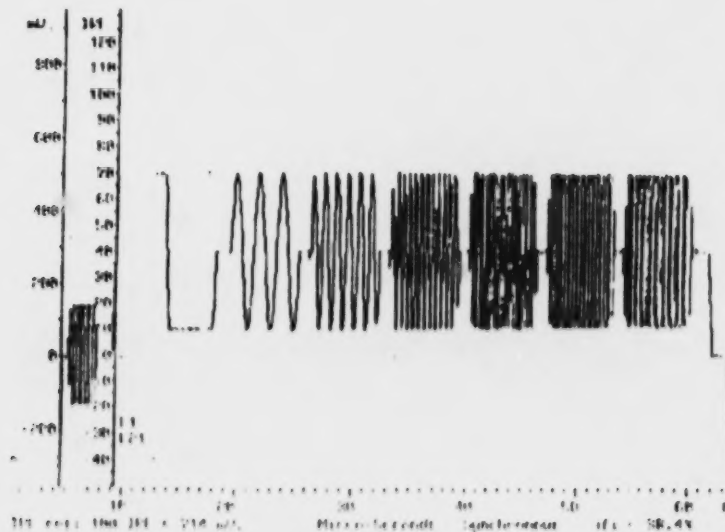
The ABL codecs handle this test with near perfection. Generally, the better the performance in this segment, the better the resolution of the compression technique -- at least in the instance of a still frame source. This is an important factor to keep in mind with our bench test. By design, the test did not take transmission time into account. Each unit was supplied with a standard signal and in 5-7 seconds, the waveform was recorded. The only control taken into consideration was that each codec had enough time to stabilize its output. The logic here is that the test should evaluate the ability of the algorithm to reproduce a quality video signal. Introducing the compression time would present a variable difficult to control considering the test environment. For this reason, each vendor's results appear approximately the same at 56Kbps or 384Kbps.

Bench Test Printouts

Standard - Color Bars - Fig. 1



Standard - Multi-Burst - Fig. 2



These are the standards by which each codec was tested. These are particularly useful when you consider what each vendor concentrates on. Some vendors try to produce fewer frames to maintain clearer images while other vendors wish to reproduce motion and vice versa.

The bench test provided valuable information about each unit, as well as about each data transmission rate tested. It was interesting to note that in the bench test, each unit performed about the same regardless of which rate was being transmitted. This is because the same algorithm appears to be used with each rate, but it is slower to react to changes in the picture at slower rates, resulting in poor video. Therefore, each test made in video quality is relatively equal. The value of the test, then, is to accurately compare units from different vendors with different coding schemes.

Direct comparisons can be made from the data collected, by overlapping the graphs and comparing the difference in waveforms. While the color bar differences appear dramatic in graphic form, the difference in the actual video produced is less noticeable. In most applications of compressed video, where the exact color representation is of little importance, these differences can be ignored. Thus, the differences between the VideoTelecom (which

produced fairly good color) and the PictureTel or CLI units (which appear less effective in color representation) is negligible. This difference will be discussed shortly.

The second portion of the bench test worth discussing involves the "multi-burst" test. In this test application, an NTSC video signal generator was used to generate a pattern which appears in video form as groups of vertical lines across the screen, as briefly mentioned earlier. Progressing from left to right across the screen, the lines get closer and closer together. They progress beyond the resolution of broadcast television to about 7 Mhz. (Standard broadcast television would reproduce these lines accurately up to about 4 - 4.5 Mhz). While the ABL DS-3 equipment, with a 2:1 compression ratio, reproduces these lines with great accuracy, the highly compressed signals with CLI, PictureTel and VideoTelecom face a much more difficult task.

VideoTelecom appears to score very well, reproducing these test patterns accurately. However, a quick look at their video presents a different story. VideoTelecom accomplishes greater resolution by transmitting fewer video frames over a given time. This results in poor motion compensation. In particular, the VideoTelecom unit performed very poorly in the teleconference/motion seg-

ments for this reason. At 56 Kbps, VideoTelecom's performance was completely unacceptable, with the possible exception of color graphics transmission.

PictureTel and CLI both have some difficulty with this test. The general result is an image which is fuzzy, compared to full-motion video. In consideration of the high levels of compression, however, both produce very good quality images. The PictureTel we tested did have a tendency to produce a fuzzier picture when dealing with motion (basketball), but it is none-the-less on the same level with CLI.

To illustrate these results, we have included a scanned image of the color bar and multi-burst test *without compression*. (See Fig. 1 & 2)

Conclusion

Laboratory experiments structured to provide data on the performance of each unit logically should substantiate the best product by simple numerical evaluation. However, in this case, the data may be misleading. The two tests used for comparison are significant in evaluating the equipment. However, these results alone would be very unreliable in selecting a quality product for an application.

Subjective observation of the performance of the codecs must be utilized to understand the results of these tests.

Low End Compression

The color bar tests (graphs found in Appendix B) show that the CLI Rembrandt most accurately reproduced color. Of the six colors, only two appear to totally miss their proper location. PictureTel is close to the Rembrandt unit with very good color reproduction. VideoTelecom performed very poorly in our lab, without coming close to any of the vectorscope "color boxes". Perhaps surprisingly, the subjective visual comparison of the three did not show dramatic differences in color representation. It is obvious that the VideoTelecom does not perform as well as PictureTel or CLI; however it produced an acceptable picture in terms of color saturation and hue. An application such as the retail clothing industry may be more critical of the results, warranting a true color reproduction.

The multi-burst test, involving vertical lines of resolution, provides interesting data. In Appendix B, VideoTelecom does a superior job of recreating the graphs. As mentioned earlier, this is because the VideoTelecom product refreshes the screen much more slowly than its com-

petitors, which gives it the opportunity to transmit a single frame with greater accuracy. CLI and PictureTel sacrifice this instantaneous accuracy to compensate for motion, which is another criterion for a quality video reproduction.

Therefore, this test alone is not a clear representation of the true quality of each codec. If we examine the results of CLI and PictureTel, it appears that the CLI unit reproduces the waveform only slightly better than PictureTel. Each set of waveforms is more accurate peak to peak in amplitude which reinforces the results from the subjective test. In side by side comparisons, the PictureTel had an inherent fuzzy quality, particularly near the outer portions of the screen. Each of these tests utilized only the motion video connections to the codecs. Had the multi-burst test used the graphic channels of the codecs, a higher quality image would result. This constraint allowed us to test each codec on the same level -- standard video quality.

High End Compression

With ABL being the only vendor to supply DS-3 (45 Mbps) codecs, it is difficult to provide information representative of the industry. It would suffice to say that between ABL's Commercial and Broadcast quality

codecs, there are significant differences in performance which are noticeable in side-by-side comparisons. As one can see from the graphs of the broadcast unit (445-B) the quality is excellent. The waveforms are almost identical to the standard graphs produced. During our study, it became very difficult to determine whether full motion video was "live or compressed". In our testing, the commercial unit performed well, but lacked the clear resolution of the broadcast unit.

Human Factors

As we worked with each codec and with the vendors, we had ample opportunity to judge the "user-friendliness" of each one. Table 1 presents the value judgements of the co-investigators regarding such concerns as the user interface, ease of installation, the adequacy of the documentation, and the quality of vendor support. The experiences and conclusions of other users may vary.

Codec Features

Table 2 provides the reader with an easy-to-read chart with the different features and interfaces available with each particular unit.

Table 1

The "Human" Factors

	A	B	C	D
ABL	8	9	5	7
PictureTel	7	8	7	9
Rembrandt	7.5	7	8	8
Rembrandt 56	7.5	7	8	8
VideoTelecom	4	6	9	8

Rated on a Scale from 1(Low) to 10(High)

A - User Interface

C - Documentation

B - Installation

D- Vendor Support

Codec Features

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Appendix A: Comparative Analysis

56 Kbps - Color Graphics

	A	B	C	D	
Color Quality	6.31	3.83	3.20	4.51	P < .000
Sharpness/Clarity	6.49	3.26	3.14	4.60	P < .000
Overall Quality	6.43	3.31	3.11	4.43	P < .000

A - Real Time Video

C- PictureTel

B - VideoTelecom

D- Rembrandt 56

(N = 35; Scale: Low = 1; High = 7, P=Probability)

56 Kbps - Teleconference

	A	B	C	D	
Color Quality	6.51	3.20	3.97	3.77	P < .005
Lighting on Subjects	6.23	3.20	3.94	4.11	P < .001
Sharpness/Clarity	6.46	3.00	3.43	4.50	P < .000
Overall Quality	6.51	2.57	3.63	4.06	P < .000

A - Real Time Video

C- PictureTel

B - VideoTelecom

D- Rembrandt 56

(N = 35; Scale: Low = 1; High = 7, P=Probability)

56 Kbps - Motion (Basketball)

	A	B	C	D	
Smoothness of Movement	6.75	2.01	2.14	3.80	P < .000
Sharpness/Clarity	6.60	3.54	2.43	3.30	P < .000
Overall Quality	6.71	2.54	1.86	3.40	P < .000

A - Real Time Video

C- PictureTel

B - VideoTelecom

D- Rembrandt 56

(N = 35; Scale: Low = 1; High = 7, P = Probability)

384 Kbps - Color Graphics

	A	B	C	D	
Color Quality	4.31	5.89	4.36	5.20	P < .000
Sharpness/Clarity	3.26	5.63	3.78	5.46	P < .000
Overall Quality	3.14	5.83	3.94	5.36	P < .000

A - VideoTelecom

C- PictureTel

B - Rembrandt

D- Rembrandt 56

(N = 35; Scale: Low = 1; High = 7, P = Probability)

384 Kbps - Teleconference

	A	B	C	D	
Color Quality	4.11	5.50	4.15	5.03	P < .000
Lighting on Subjects	3.60	5.54	4.11	5.00	P < .000
Sharpness/Clarity	3.46	5.14	4.31	4.94	P < .000
Overall Quality	3.51	5.45	4.31	5.05	P < .000

A - VideoTelecom

C- PictureTel

B - Rembrandt

D- Rembrandt 56

(N = 35; Scale: Low = 1; High = 7, P = Probability)

384 Kbps - Motion (Basketball)

	A	B	C	D	
Smoothness of Movement	2.71	4.10	4.23	4.34	P < .000
Sharpness/Clarity	4.06	4.75	4.26	4.63	P < .020
Overall Quality	3.26	4.23	4.11	4.15	P < .007

A - VideoTelecom

C- PictureTel

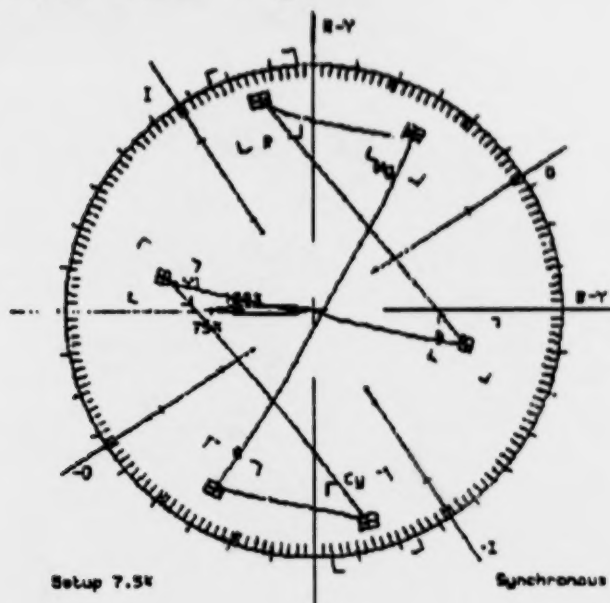
B - Rembrandt

D- Rembrandt 56

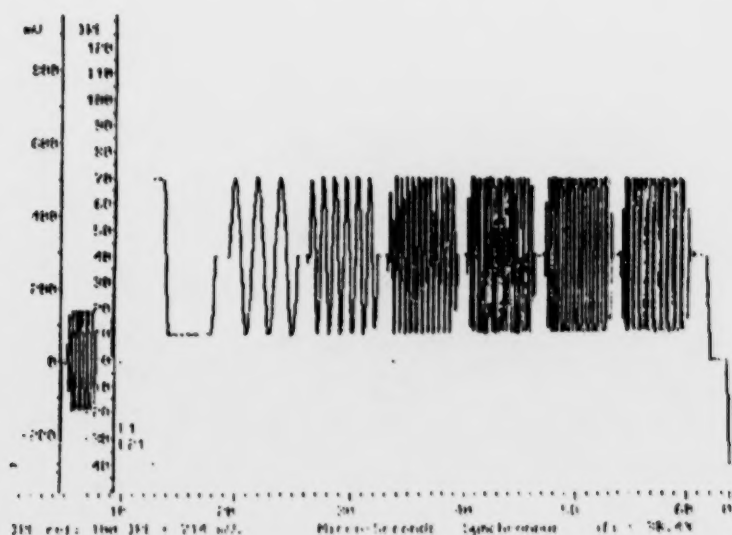
(N = 35; Scale: Low = 1; High = 7, P = Probability)

Appendix B- Bench Test Printouts

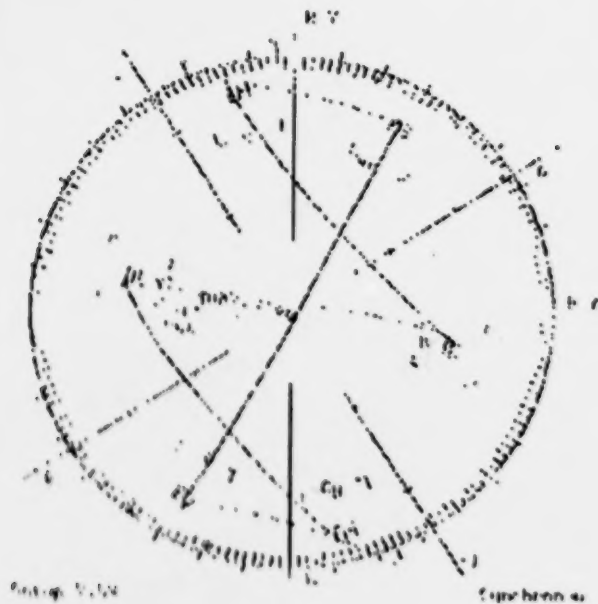
Standard - Color Bars - Fig. 1



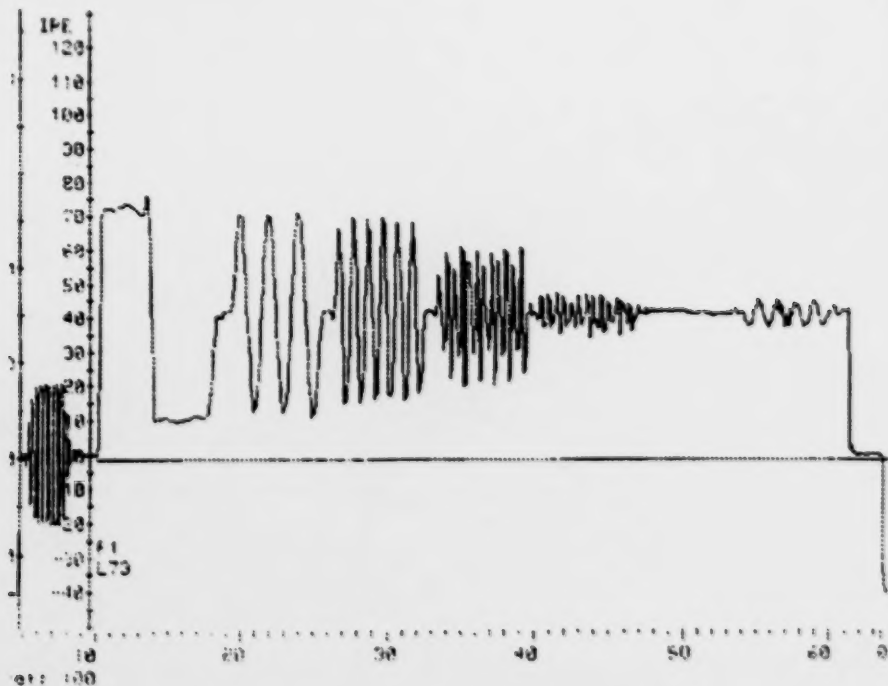
Standard - Multi-Burst - Fig. 2



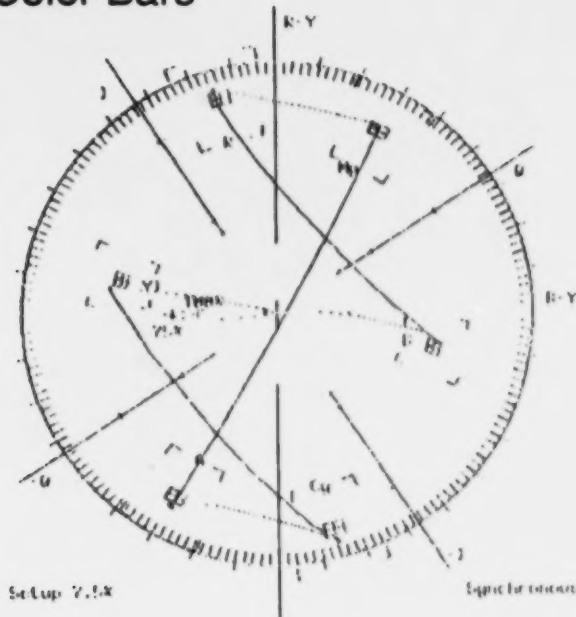
PictureTel C-3000 - Fig. 3
(56 Kbps) - Color Bars



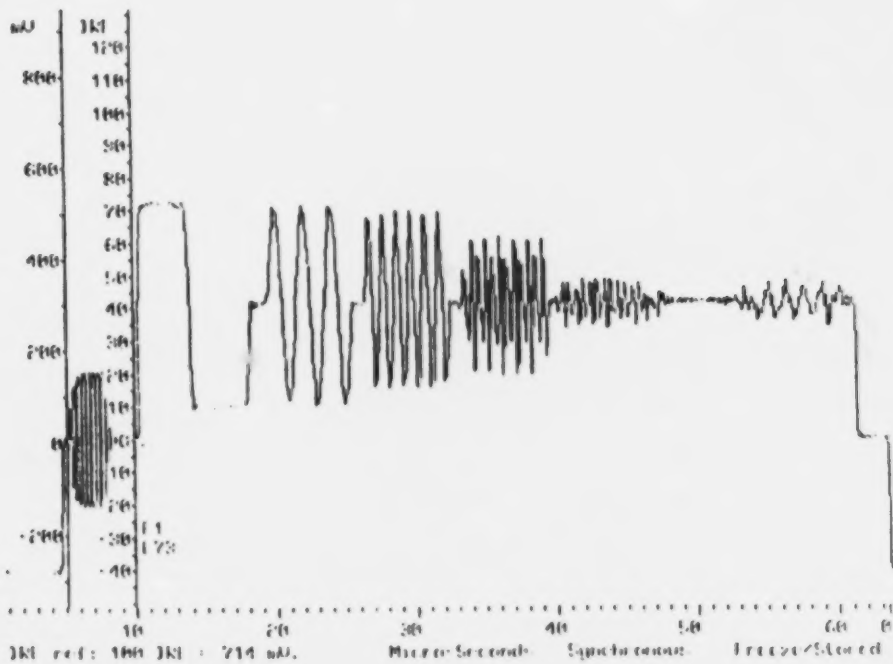
PictureTel C-3000 - Fig. 4
(56 Kbps) - Multi-Burst



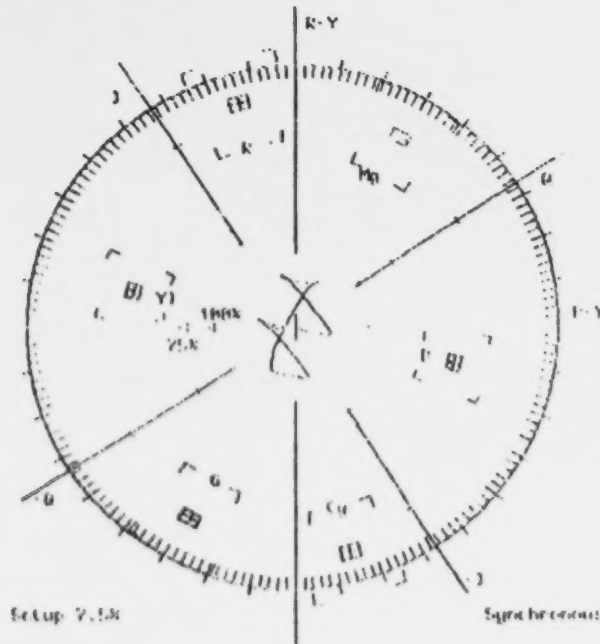
PictureTel C-3000 - Fig. 5
(384 Kbps) - Color Bars



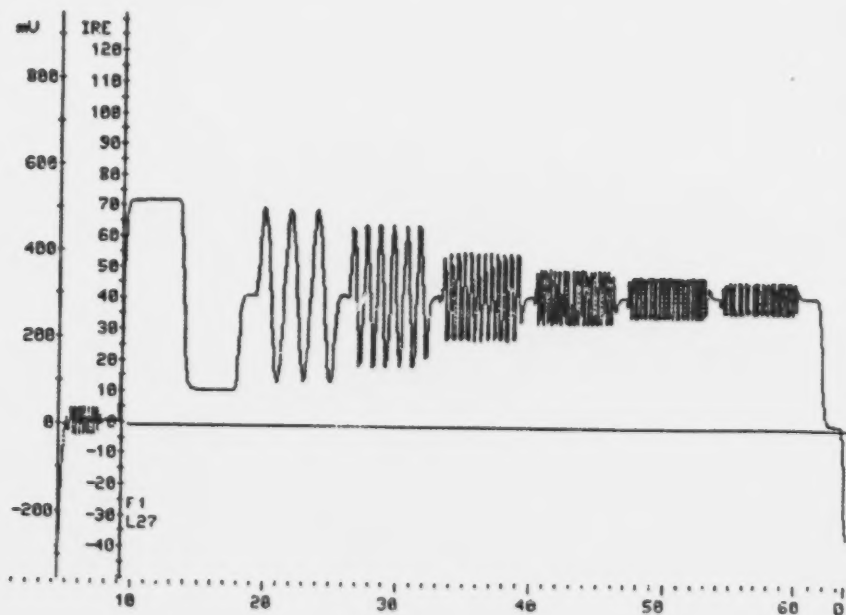
PictureTel C-3000 - Fig. 6
(384 Kbps) - Multi-Burst



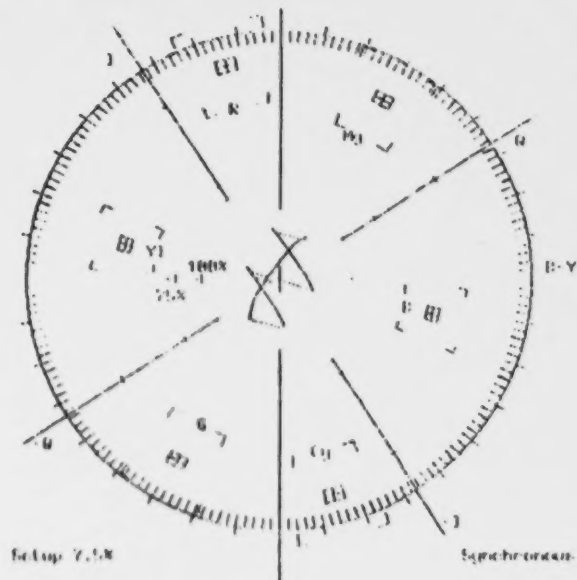
VideoTelecom CS200 - Fig. 7
(56 Kbps) - Color Bars



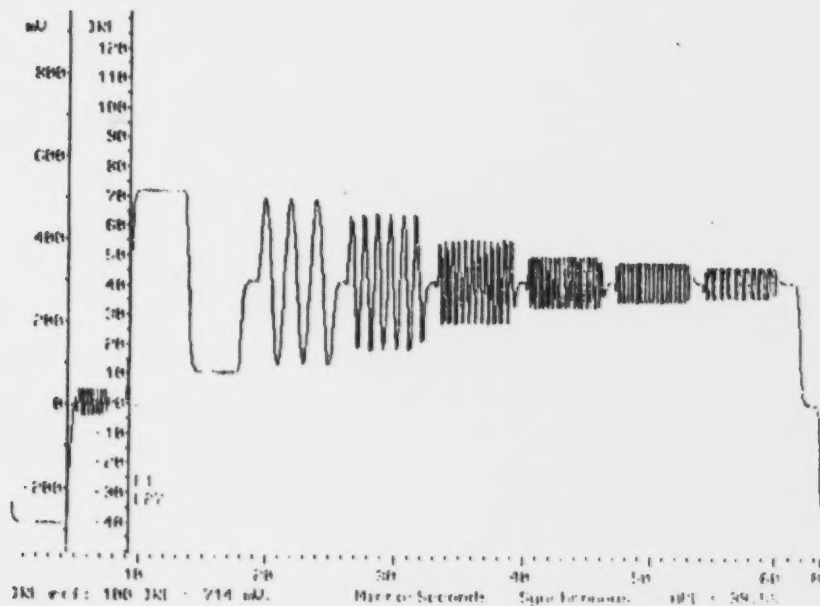
VideoTelecom CS200 - Fig. 8
(56 Kbps) - Multi-Burst



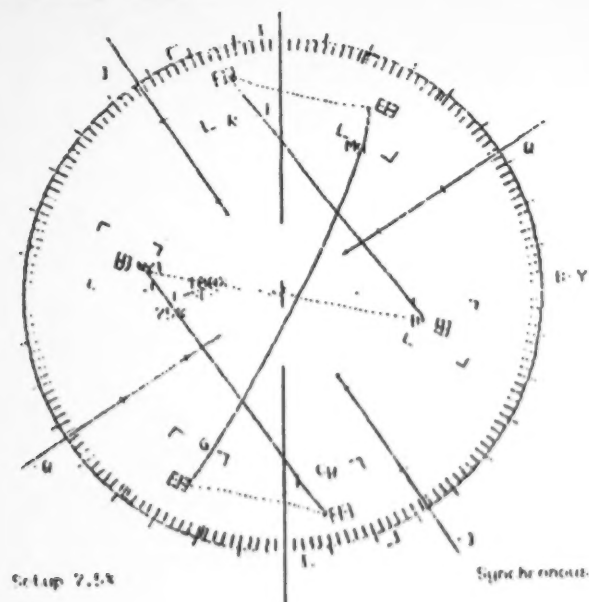
VideoTelecom CS200 - Fig. 9
(384 Kbps) - Color Bars



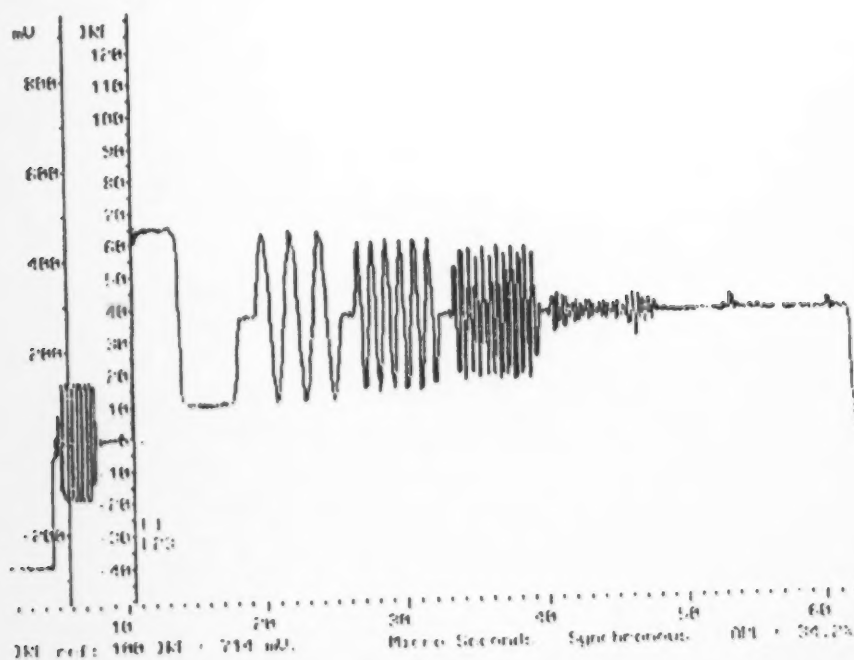
VideoTelecom CS200 - Fig. 10
(384 Kbps) - Multi-Burst



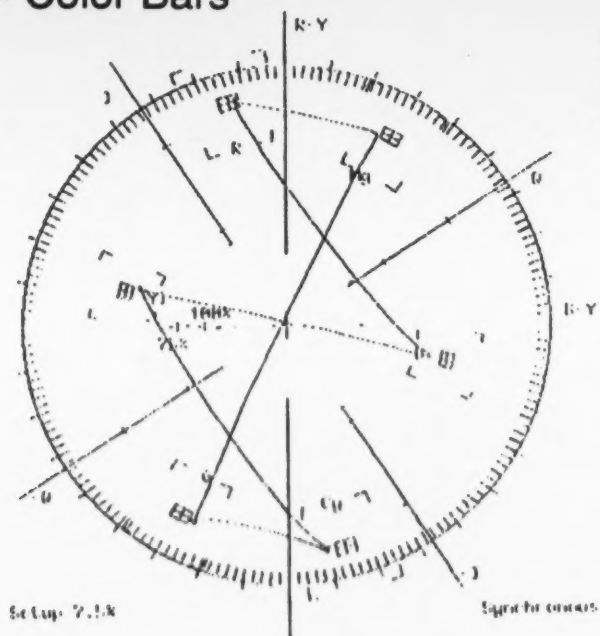
Rembrandt - Fig. 11
(384 Kbps) - Color Bars



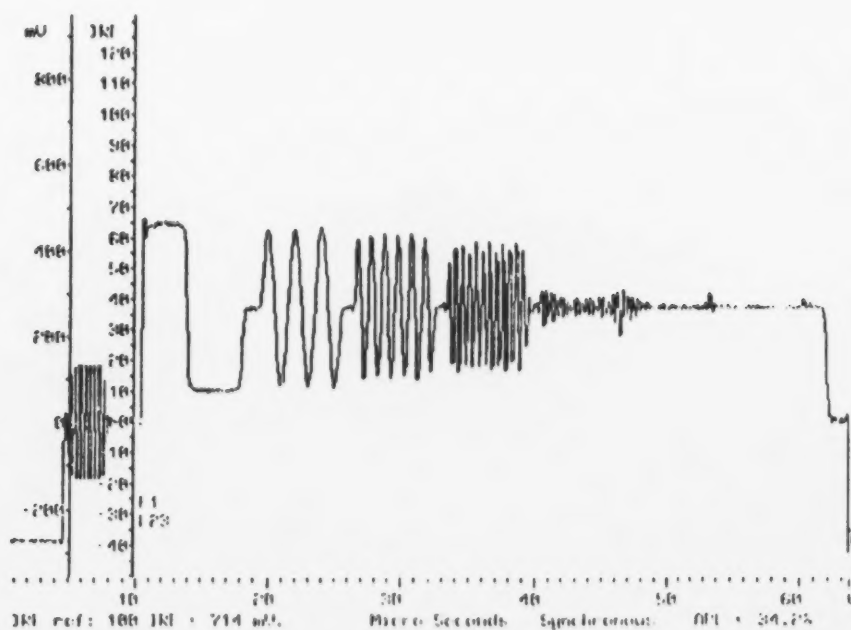
Rembrandt - Fig. 12
(384 Kbps) - Multi-Burst



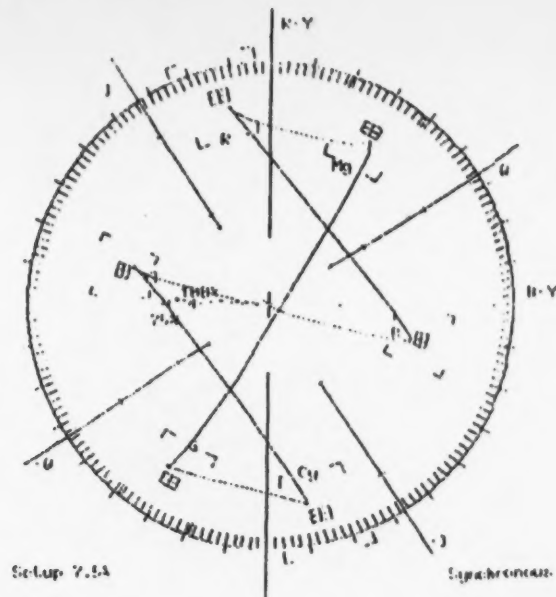
Rembrandt - Fig. 13
(1.5 Mbps) - Color Bars



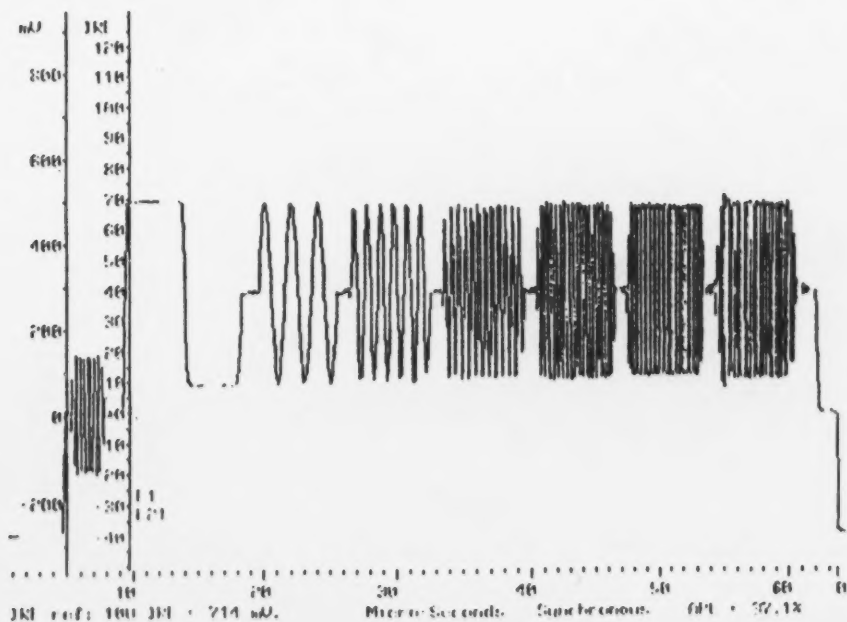
Rembrandt - Fig. 14
(1.5 Mbps) - Multi-Burst



ABL Engineering - VT445B - Fig. 15
(45 Mbps) - Color Bars



ABL Engineering - VT445B - Fig. 16
(45 Mbps) - Multi-Burst



Appendix C: Vendor Information

ABL Product Description

VT 445B

According to the vendor, the "Widecom VT 445B" is a high performance digital transmission system for broadband services of video, audio and data signals. The unit operates at 45 Mbps (44.736 Mbps) with capability of simultaneous transmission of a full motion 4.5 Mhz video signal and two 15 Khz audio signals. It is directly interfaceable with common carrier transmission equipment and is versatile enough to fit applications in video teleconferencing, local loop applications, and point-to-point transmission. And the layout of the system is based on modular plug-in units that allow for easy reconfiguration of alternative transmission paths.

VT 445C

The VT 445C is the commercial counterpart to the broadcast quality VT 445B. The VT 445C is also a high performance digital transmission system for broadband services. Like the VT 445B it operates at 45 Mbps with the capability of simultaneous transmission of a full motion 4.5 Mhz video signal and two 15 Khz audio signals. Both the VT 445B and VT 445C units are configured in a low profile of 6 inches in height, 19 inches in width, and 12 inches in depth.

ABL Academic Applications

ABL has a number of academic applications in place including projects with the State of Iowa, the Government of Spain and the Government of Denmark. The company also has done extensive work with a majority of the common carriers in the U.S. in developing applications. Anyone interested in learning more about these applications can call Bruce Gravens at ABL Engineering, Inc. at (216) 974-8585.

ABL Price List

VT445B \$12,727.00 (per unit)

VT 445C \$7,500.00 (per unit)

Compression Labs, Inc. Product Description

Rembrandt

The CLI Rembrandt is a fully contained codec. Its major features include the following:

- Communications
 - Network Interfaces : T1, NTT T1, G732, RS-449, V.11
- Transmission rates: 384 Kbps - 3.1 Mbps
- Video resolution: 576 x 368 pixels
- Audio: XLR balanced impedance 600 ohms
- RS-232 data channel for external data communications
- Connection for input and output video
- Graphic video interface
- RGB and composite video interfaces
- Encryption for secure transmission facility
- Control through front panel keys or ASCII terminal (local or remote)

The Rembrandt is a self-contained codec which, the vendor states, is designed for a lasting investment. The unit features front panel controls which eliminate the need for a terminal interface to control the codec, although it has the capability. The codec provides access to the large circuit boards which are installed according to the configuration ordered from CLI. Different configurations might include specific interface cards to customize the system to the network or special motion compensation circuitry necessary for an application.

The codec is ready for operation almost immediately after powering the unit for faster recovery time from power or network failures. This is due to ROM based firmware

used in initializing the system. CLI provides a multitude of network interfaces and connectors for video and graphics inputs and outputs. The system may use either RGB or composite video interfaces, making it adaptable to more advanced video applications. This is an especially nice feature for graphics input or high quality video transmission.

This system uses XLR connectors for audio connection which may require wiring special cables for a unique application. There are delay controls to adapt the audio for the specific transmission rate used. Control of the audio volume is also available through the codec.

Rembrandt 56

The Rembrandt 56 is identical to the Rembrandt unit in terms of design and operation. It does provide RGB and composite video connections, but it has only one set of video interfaces, input and output. The unit offers data transmission and remote control capabilities, just as the Rembrandt unit does. Its major difference is, of course, the transmission rates. It operates from 56 Kbps to 384 Kbps.

CLI Academic Applications

Higher Education Applications

Penn State University

Contact: Dave Phillips

Phone: 814-863-0885

Application: Inter-campus, multi-function.

University of Colorado

Contact: Dorothy Jackson

Phone: 301-492-6331

Application: Training link to Martin Marietta Continuing Education (EE, Computer Science).

University of Missouri

Contact: Bernie Sarchet

Phone: 314-341-4688

Application: Inter-campus link for graduate engineering.

University of Minnesota

Contact: Fred Street

Phone: 612-624-9533

Application: Training link which carries U-M Unite curriculum between Minneapolis and Chippewa Falls, WI (EE, Computer Science).

Columbia University

Contact: Peter Shapiro

Phone: 212-280-2993

Application: Training link to IBM (upstate NY) for continuing education.

Vermont Technical College

Contact: Daryl Thompson

Phone: 802-728-3391 Ext. 341

Application: Using multipoint distribution capability for classes.

West Virginia No. Community College

Contact: Chuck Julian

Phone: 304-223-5900

Application: Distance teaching between two community college locations.

Dallas County Community College System

Contact: Jim Hill

Phone: 214-746-2436

Application: Distance teaching among several community college locations.

Applications

Instruction - For example, offering a graduate level program to a campus that doesn't offer such a class, or to private industry.

Administration - Administrative planning meetings, fund raising, department meetings.

Training - Internal university training for personnel development (i.e. interpersonal communications, retirement)

Research - Link to private industry or to the U.S. government or joint or contracted research projects

Benefits

- Increase tuition base by adding classes and by expanding to new markets (i.e. private industry)
- Maximize use of valuable faculty resources
- Reduce travel expense
- Improve academic products (classes)

CLI Price List

Equipment Prices Rembrandt Codec

Bandwidth - 384 Kbps to 3.1 Mbps

Rembrandt Full Duplex Codec (\$68,000), composite graphics w/ 480 lines x 368 pixels resolution (\$5,000), Encryption - DES standard (included)

Total Rembrandt full duplex codec	\$73,000
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Options

Two RS-422/449 user data ports for additional data interfaces up to 448 Kbps aggregate speed	\$2,500
--	---------

RGB graphics interface provides 480 lines x 736 pixels resolution (this is in lieu of the composite graphics interface)	\$6,000
---	---------

Video switcher with Simulvision accepts up to 8 video sources (6 motion and 2 graphics) for video switching and continuous presence allowing 2 motion video sources to be combined and transmitted simultaneously	\$7,000
---	---------

Gallery 2000 Movable Module Videoconference Room System	\$30,000
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Site Pricing

Rembrandt Codec	\$73,000
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Gallery 2000 Room System	\$30,000
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Total per site using Package Pricing	\$95,000
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Rental Pricing

Monthly Rental Program

Gallery plus Rembrandt Codec

\$4,000/mth

This rate applies to months 1, 2 and 3. Months 4 through 12 the rate is \$8,000/mth. A conversion to purchase at 30 days earns a 90 percent rental credit toward a purchase, at 60 days a 75 percent credit, and at 90 days a 60 percent credit.

Installation

Installation is \$2,000 per site or the same as the charge for a purchase.

Equipment Prices

Rembrandt 56 Codec

Bandwidth - 56 Kbps to 384 Kbps

Rembrandt 56 Full Duplex Codec (\$30,000), composite graphic w/ 480 lines x 512 pixels resolution (\$5,000), one RS-422/449 user data port used for an additional data interface for speeds up to 112 Kbps (\$2,500), a second V.35/RS-366 interface for dual operation of 112/128 Kbps (\$1,000), encryption - DES standard (included)

Total Rembrandt 56 Full Duplex Codec

\$38,500

Options Included in Rental Units and Most Frequently Purchased on the Codec

Eight Kbps audio option for use in embedded audio providing an additional 8 Kbps of bandwidth for use by the video signal, i.e. 56 Kbps = 48 Kbps video plus 8 Kbps audio. Most valuable at 56 and 112 speeds. (\$500)

Gallery 2000 Movable Module Videoconference Room System including front cameras with pan/tilt capability; two 25" monitors; complete audio system with amplifier; echo canceller, speaker, three microphones; graphics stand, cabinet, and remote control unit (\$30,000)

Site Pricing

Rembrandt 56 Codec	\$38,500
Gallery 2000 Room System	\$30,000
Total per site using Package Pricing	\$49,500
Installation cost per site	\$2,000

Rental Pricing

Program 1 - One Year Lease/Rental Program

Gallery plus Rembrandt 56 \$3,500/month

Minimum rental is one year unless converted to purchase. Cost to break contract is 6 months rental or whatever is remaining on contract, whichever is less. Seventy percent of one year rental may be applied against the purchase price of in-place equipment. Ninety day warranty on equipment purchased in-place at the end of the rental period (effectively a 15 month warranty from inception of rental).

Program 2 - Monthly Rental Program

Gallery plus Rembrandt 56 \$4,000/month

This rate applies to months 1, 2 and 3. In months 4 through 12, the rate is \$8,000/month. A conversion to purchase at 30 days earns a 90 percent rental credit toward purchase, at 60 days a 75 percent credit, and at 90 days a 60 percent credit.

The second program is principally for those who desire a short term rental and is so structured. Program One is aimed toward long term rental and presents a nice alternative to a user who may be short of capital for a purchase.

Installation is \$2,000 per site or the same as the charge for a purchase.

Educational Discounts

An educational discount of 12 percent is applicable to any of the list prices for equipment, but does not apply to the prices for packages including the Gallery 2000 System.

PictureTel Product Description

PictureTel C-3000 Video Codec

The C-3000 is a software-based codec capable of compressing video and audio signals and merging them with data signals for transmission over digital transmission media. The unit is available as either a stand-alone or rack-mounted unit. The software is based in a cartridge that is inserted into a slot on the front of the codec giving the user flexibility in adapting to new compression technology by obtaining a new software cartridge.

This unit ranges in compression from 1.2 Kbps to 384 Kbps. Compression at 1.2 Kbps would allow for transmission of freeze frame images over standard voice-grade telephone lines using a modem. A variety of transmission media can be used including dial-up/non-dialed digital (leased or private) lines, satellite, microwave and T1 circuits.

PictureTel's video compression technology utilizes HVQ (Hierarchical Vector Quantization) and is compatible with either NTSC or PAL video signals. Audio can either be compressed and transmitted in-band or distributed externally on a separate medium. An audio delay allows the user to delay the audio from 0 to 2000 milliseconds for synchronization.

The system has a variety of control options for the user. The keypad on the front of the unit is the primary control system, but external control is available to allow for remote control and diagnostics. The network control port can be used alternatively as a data side channel transmitting at speeds from 300 bps to 19.2 Kbps.

The codec's channel interface is set for use with either EIA RS-449, CCITT V.35, or CCITT X.21 CSUs. The codec is capable of sensing the network clock signals and adjusting its transmission accordingly.

A variety of monitoring and diagnostic features includes power-up self-test, loop-back tests, module tests and test patterns. Real-time diagnostics continually monitor the codec's operation, displaying errors on-screen as they arise.

Additional options available include:

Two-Channel Operation - This features allows for the utilization of a second channel interface so that the codec can send and receive over two channels at speeds of up to 64 Kbps per channel.

Multipoint - This allows for one codec to transmit to several locations simultaneously or to receive a multipoint conference from several different locations.

Encryption - Users have the ability to encrypt the transmitted signal for increased security. Three different methods of encryption are available.

Video Graphics Interface - An optional graphics interface card allows for transmission of individual frames at a resolution of 512 x 480 pixels. Input and output interfaces include composite or Y/C video formats.

Data Interface - Optional data interfaces can add up to four data channels within the compressed signal. Interfaces include two RS-232C and two that can be RS-232C, RS-449, or V.35.

PictureTel Academic Applications

In the past PictureTel has primarily focused on the business market. Currently they do not have any academic applications but have expressed interest in working with the academic market.

PictureTel Price List

V-2050 Videoconferencing System

C-3000 codec with HVQ software and videoconferencing console with full duplex audio, one microphone, fixed camera, 20" monitor, 5" B&W preview monitor.

\$34,900

Options: 25" monitor \$1,050, encryption \$500, auxillary data ports (dual RS-232C, dual RS-449) \$3,500, dual channel interface w/o CSU \$980, channel interface with CSUs & cables \$5,680.

V-2100 Videoconferencing System

C-3000 codec with HVQ software and videoconferencing console with full duplex audio, one microphone, video switching, call setup, room control, room camera with pan/tilt/zoom and auto focus, 20" color monitor.

\$44,900

Options Pricing

25" monitor \$1,050, additional microphones \$250, multipoint/add-on \$6,950, videographics system with 20" monitor \$8,700, videographics system with 25" monitor \$9,750, encryption \$500, document camera \$3,300, auxiliary data ports - dual RS-232C, dual RS-449 \$3,500, dual channel interface w/o CSU \$980, dual channel interface with CSU & cables \$5,680, single channel interface with CSU & cables \$2,350.

Installation

V-2050 or V-2100

\$3,000

V-3100 Videoconferencing System

C-3000 Codec with HVQ software, full duplex audio, one microphone, solid state CCD color room camera with pan/tilt/zoom and auto focus, call set up, conference, and maintenance controls. Standard features included in this system are 25" Sony PVM 2530 monitor, windowing, auto preview, Echo Erase.

\$54,900

Options

Additional tabletop microphones \$250 each, lapel microphone \$300, far end camera control \$2,000, videographics \$4,800, videographics w/2nd monitor \$9,750, document camera \$3,300, tripod camera - fixed \$4,700, tripod camera - remote PTZ \$6,750, encryption \$500, broadcast multipoint \$1,950, interactive multipoint with phone add-on \$6,950, phone add-on \$5,000, auxiliary data ports - dual RS-232C, dual RS-449 \$3,500,

dual channel interface w/o CSU \$980, dual channel interface with CSU & cables \$5,680,
single channel interface with CSU & cables \$2,350.

Installation

V-3100	\$3,000
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C-3000 Codec Price

C-3000 Codec	\$26,500
HVQ Software	\$3,000

Options

Dual channel interface \$980, encryption \$500, multipoint \$1,950, auxillary data ports -
dual RS-232C and dual RS-449 \$3,500, videographics \$4,800, RGB interface for VGI
(Videographics Interface) \$2,000.

Installation

C-3000	\$2,000
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VideoTelecom Corp. Product Description

VideoTelecom Corp. CS-200

The CS-200 is a complete self-contained conferencing unit, including camera, monitors and the following:

- Built-in codec with 56 Kbps to 768 Kbps transmission rate
- RS-449/RS-422 Network Interface
- Selectable in-band or out-of-band audio
- Tabletop microphone (standard)
- Two microphone inputs
- Main and auxiliary camera inputs
- Menu driven user interface
- Built in diagnostics
- VCR connection for playing or recording video
- RS-232 data channel for external data communications
- Rack mount option
- PC based 386 architecture
- Software control / driven

"With the VideoTelecom Conference System 200, you get a go-anywhere, flexible, long distance video system that puts conferencing where you work. The CS-200 with its unique built in codec for video telecommunications and built in full duplex audio system is a low-cost multi-purpose conference system ready to move and install at a moment's notice."

-VideoTelecom brochure

The VideoTelecom system is directly menu driven with a PC keyboard interface for the codec. The menus appear on the video screen showing choices ranging from connecting video and/or audio calls, changing transmission rates, setting volume level, and adjusting audio echo cancellation. The system is somewhat slow moving from screen to screen; however after the system is configured for a specific purpose, the setup is saved to disk and will boot up with identical settings for future use.

The audio system utilizes XLR connectors for microphones but uses RCA phone plugs to easily interface additional VCRs or monitors with external audio connectors. Control of the audio through the system is adequate for a teleconferencing environment.

VideoTelecom Corp. Academic Applications

The following list of colleges and universities currently have VideoTelecom Corp. equipment in place and working. The majority of the installations are associated with a Video Placement project, which uses VideoTelecom equipment. Individuals interested in the Video Placement project can contact Vincent Cogliano (President) or Steven Cogliano (Vice President) at Video Placement, (617) 482-6672.

Oklahoma State University
Stillwater, Oklahoma

Georgia Institute of Technology
Atlanta, Georgia

USAISC
Georgia Institute of Technology
Atlanta, Georgia

Atlanta University
Atlanta, Georgia

University of Tennessee
Knoxville, Tennessee

Purdue University
West Lafayette, Indiana

California Institute of Technology
Pasadena, California

Units Currently Awaiting Transmission Connections:

Pennsylvania State University
Cornell University
University of Florida, Gainesville
Syracuse University
Iowa State University
Howard University
Arizona State University
Prairie State University
University of Illinois, Urbana
University of Houston
North Carolina Agricultural and Technical
Rochester Institute of Technology
San Jose State University
University of Kansas
San Diego State University
Michigan Technical University

VideoTelecom Corp. Price List

Conference Systems*

All prices are list.

Model CS200 - Conference System 200. Complete turnkey, full-motion remote video conference system. Includes full-motion video compression at 56 - 768 Kbps (user selectable), full-duplex audio with automatic echo cancellation, one tabletop microphone, one CCD camera with manual zoom lens, one 20" video monitor, multiple camera inputs, VCR input and output, software and software license. Group or desktop conferences.

Price - \$33,950.00

Model CS250 - Same as CS200 but does not include camera, monitor, or a tripod.

Price - \$29,950.00

Model CS300 - Conference System 300. Complete turnkey full-motion remote video conference system. Includes full-motion video compression at 56 - 768 Kbps (user selectable), full-duplex audio with automatic echo cancellation, an IBM-AT compatible personal computer with 20 Mbyte hard drive, two 20" video displays, two cameras (main camera is CCD with manual zoom), two desktop microphones, handheld room controller, VCR input and output, facsimile port, printer port, software and software license. Group conferences.

Price \$41,500.00

Model CS325 - Same as CS300 but substitutes 25" monitors for 20" monitors.

Price - \$43,500.00

Model CS350 - Same as CS300 but does not include cameras, monitors or tripods.

Price - \$35,000.00

Model CS400 - Full-motion video network codec. Video compression at 56-768 Kbps (user selectable). Interfaces with the VBX (see below) to the network to support multi-way interactive videoteleconferences.

Price - \$35,000.00

Model VS100 - Voice System 100. Fits into IBM compatible personal computer to make it a full-duplex audio teleconferencing system with acoustic echo cancellation. The user may talk on the VS100 while using the PC. Includes full-duplex DSP-based audio card, speaker, microphone with internal pre-amplifier, cables, software, software license, and user guide.

Price - \$3,300.00

- Cable, installation, freight, taxes, insurance, duties and service not included. Prices and equipment subject to change without notice. Prices are for U.S. customers only. All VTC components carry a 1-year warranty.

Support Products

Model VBX - Video Branch Exchange. Facilitates multiway videoconferences for several sites to interact simultaneously. Includes Network Control Software to allow for multiway meetings through a central reservation and operator system.

Price - \$30,000.00

Model RA25 - Cabinet on casters. Black with plexiglass doors. MR20/MR25 electronics rack mounts inside. Video equipment can be positioned on top.

Price - \$2,500.00

Options for Conference System 300

Required - video switcher \$1,000, mike pre-amp and mixer & microphones \$500, audio noise gate \$700, acoustic echo canceller \$4,700

Additional Options Available - Time-base corrector for use with VCR \$5,000, video graphics store and send \$5,000, room controller \$3,000, PC with computer send screens and files \$3,000, and fax port.

Multiplexers

The following descriptions are for products provided by Timeplex and Teltone for our testing. For further information, interested individuals can find addresses at the end of this report.

Timeplex - Microlink/2 Data Voice Network Exchange

The Microlink/2 provides the building blocks of multiexchange T1 and other high capacity networks carrying substantial voice traffic along with data communications. It offers comprehensive and flexible management of voice and data connections. Features include: integration of voice and data; up to 160 exchanges per network; DS-0 time slot interchange capability for routing D4 formatted voice channels; compression of PCM digitized voice to ADPCM on a group or individual channel basis; and comprehensive network management via a microcomputer based system.

Teltrend - MAX1

The MAX1 is a byte-interleaved T1 multiplexer capable of interfacing voice and data devices to two T1 spans per unit. MAX1 provides highly efficient use of T1 spans for voice and data connection on a point-to-point or multipoint basis, and is compatible with PSTN (Public Switched Telephone Network) services for point-to-point applications. Features: provides all output voltages required by the MAX1, including -48VDC relay and talk battery (no separate - 48VDC source needed); two supplies operate in load sharing mode, with full redundancy; an early power fail warning enables orderly shutdown; overvoltage and overcurrent protection; voltage monitors for each output

voltage; meets UL and FCC requirements (Note: MAX1 Multiplexer was initially provided by TelTone, but product line was then purchased by TelTrend).

Acknowledgements

We would like to thank a number of people, without whose help this project would not have been possible. First, a special thanks to Dr. Richard Stowe, Assistant Director for the Center for Information and Communication Sciences, and Dr. Robert Yadon, Director of the Applied Research Institute and faculty member at the Center, for their guidance and help in pulling all the loose ends together. Thanks also goes to Dr. Tom Harris for his help with the statistical analysis.

Special thanks goes to Tim Beekman and John Lepley from Dynacom for their support, time and assistance in letting us borrow a 150-Mhz Dynair video switch for our DS3 test. Also a big thanks goes to our friends at Timeplex, Matt Barnes and Jeff Jensen, who donated not only equipment, but much of their valuable time, advice and support in interfacing with the multiplexer. We also appreciate all the help from Bob Rader and the engineers in Media Services at Ball State University during the project.

Most importantly, we would like to thank all of the vendors that supplied us with equipment to test. In many cases, this required herculean efforts to alter schedules, delay deliveries to customers, locate units where seemingly none existed, and otherwise "pull rabbits out of hats." Without their understanding and work this project would have never gotten off the ground. We feel that all parties involved will benefit from our attempt to share what we have learned about this up and coming technology.

For More Information

ABL Engineering, Inc.
6801 Hopkins Road
Mentor, Ohio 44060
(216) 974-8585

Compression Labs, Inc.
2860 Junction Avenue
San Jose, CA. 95134
(408) 435-3000

PictureTel Corporation
One Corporation Way
Peabody, MA 01906
(508) 977-9500

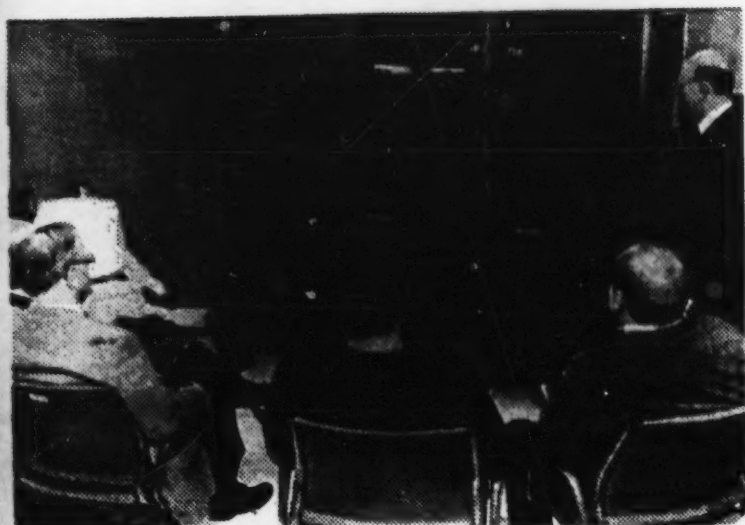
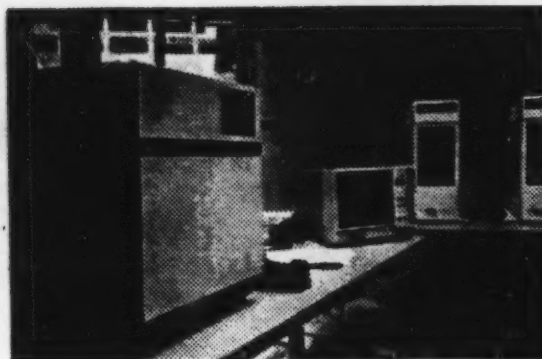
TelTone Corporation
10801-120th Avenue NE
Kirkland, Washington 98033
(206) 827-9626
(Note: MAX1 Multiplexer was initially provided by TelTone,
but product line was then purchased by Teltrend)

Teltrend
620 Stetson Ave.
St. Charles, Ill. 60174
1-800-TEL-TREND

Timeplex
400 Chestnut Ridge Road
Woodcliff Lake, New Jersey 07675
(201) 930-4600

VideoTelecom Corp.
1908 Kramer Lane
Austin, Texas 78758
(512) 834-9734

Codec Tests Proceed at the Applied Research Institute





Ball State University

Academic Affairs
Center for Information and Communication Sciences

December 4, 1989

Dear Colleague:

We hope that you found value in the "Comparative Study of Compression Video Technology" produced here in the Center.

The field of video compression is undergoing a series of rapid and mainly positive changes just now, as was clearly evident at the meeting of the National University Teleconference Network and Telecon IX in San Jose a few weeks ago. In order to share some of the more significant developments reported there, I have put together the enclosed "Update on Compressed Video" and am sending it along to you as a supplement to the report you have already received.

Sincerely,

Richard Stowe
Assistant Director

cc: Dr. Robert Yadon

Encl

November 21, 1989

UPDATE ON COMPRESSED VIDEO

Prepared for the National University Teleconference Network
by Richard Stowe
Center for Information & Communication Sciences
Ball State University

Compressed video continued to be a "hot" topic at the NUTN Annual Meeting and at Telecon IX in San Jose in late October. The following points update the information contained in "A Comparative Study of Compression Video Technology" prepared here at the Center.

Item 1 - VideoTelecom has issued a new pricing sheet (enclosed) which clarifies the cost of their System 300.

Item 2 - PictureTel pointed out that most sales of "low end" codecs are for the 112 Kbs transmission rate, not the 56 Kbs rate which we included in our tests. The vendors achieve the 112 rate by using two 56 Kbs telephone lines, with the output from one codec travelling on one line, and output from the other travelling on the other line (full duplex). Our tests basically simulated one-half of this arrangement (in other words, we were set up in simplex mode). Our results should be fully applicable to duplex transmissions at 112 Kbs.

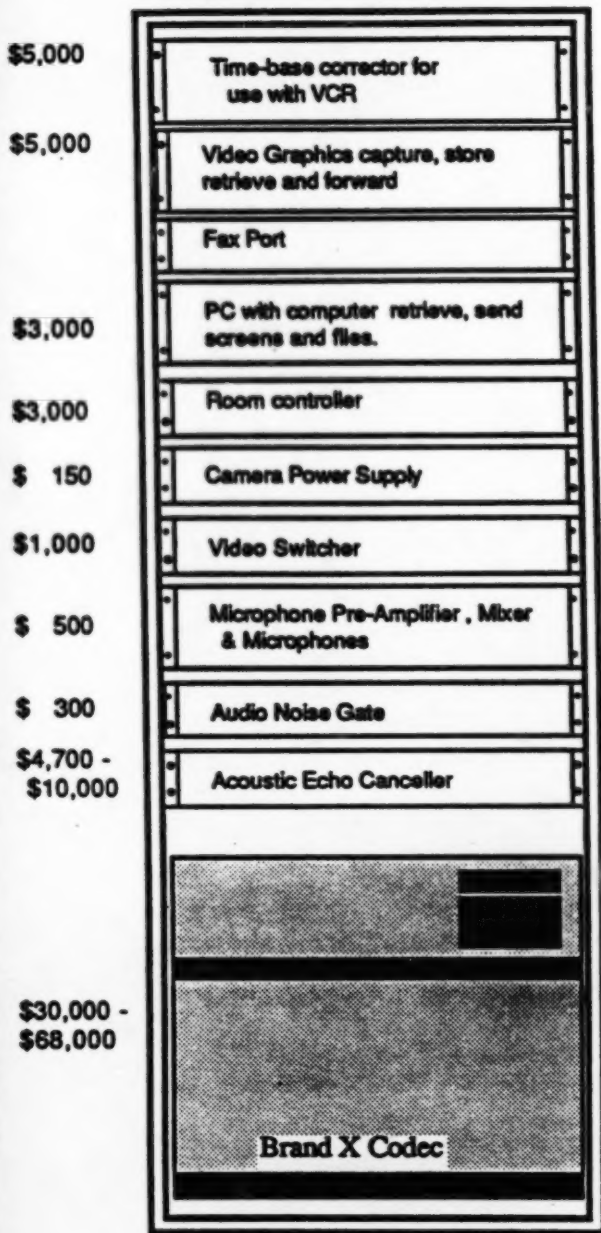
Item 3 - One vendor informed us that, by examining factors such as color saturation, motion, and resolution, our report may have given potential users a false impression of the quality of compressed video. Our intention, of course, was just the opposite: to call attention to the surprising quality of the signal which can be economically carried on a remarkably small bandwidth! Our vendor friend pointed out that most regular viewers of compressed video quickly forget about small sacrifices of color, motion, or resolution, and that is undoubtedly true.

However, the customer should continue to be aware that occasional (not frequent) viewers will usually be distracted by these factors, at least initially. Also, some situations remain (for instance, when critical detail cannot be seen) when a tightly compressed signal simply will not meet the audience's needs. As the report suggests, your application should drive your choice of the technology and the product.

Item 4 - Our apologies to GPT Video Systems for not including them in our tests. Their products have not been as well-known in the U.S. as in Europe, but are attracting attention. If you are looking for a system which, GPT asserts, is in conformity with CCITT specifications H110 and H120, or if you need a multipoint control unit, you may wish to contact John Taylor, GPT Video Systems, 1215 Jefferson Davis Highway, Suite 900, Arlington, VA 22202-3252.

Item 5 - The proposed Px64 standard for interconnecting codecs attracted much attention at Telecom IX, and on the convention floor PictureTel and VideoTelecom linked their devices together in what they said was the first public demonstration of such a linkage between codecs of different manufacture. The standard is expected to be adopted in Tokyo this month, and should give considerable impetus to the codec marketplace.

Brand X: Component Approach



VideoTelecom: Integrated Solution

VideoTelecom Conference System 300



\$35,000

All the functionality on the left is included in the CS300. Other brands require a rack full of equipment, as shown on the left, to meet the standard functionality provided by the CS300 in one compact lightweight unit.

Available options in the CS300 unit:

1. Pen Pal Graphics™ with graphics tablet for interactive draw, type, and erase annotation.
3. DES encryption
4. User RS-449 Data Port

VideoTelecom Integrates Complete Conferencing Capability into One Compact, Low-cost Unit

Technical Report

A COMPARATIVE STUDY OF COMPRESSION VIDEO TECHNOLOGY

The definitive technical report, "A Comparative Study of Compression Video Technology," is now available from the Applied Research Institute of the Center for Information and Communication Sciences at Ball State University. This full (100 page) report contains valuable background information on a rapidly-emerging technology and gives the results of comparative bench and field tests of the leading codecs.

Copies of the printed report are priced at \$25.00 each, including shipping.

The Institute has also prepared a VHS video cassette showing the video output from each of the codecs across its range of transmission rates. Each codec was tested with identical video sources representing video graphics, teleconferencing, and rapid motion. The tape is useful for making visual comparisons among the products and also for evaluating the various transmission rates for individual applications.

The video cassettes may be ordered at a cost of \$25.00 apiece, including shipping.

For \$45.00 a package deal is available which includes a copy of the report and one VHS tape (Includes shipping).

ORDER FORM

Please send me _____ copies of the printed report "A Comparative Study of Compression Video Technology" at \$25.00 each (including shipping).

Please send me _____ copies of the accompanying VHS video tape at \$25.00 each (including shipping).

_____ technical reports @ \$25.00.....\$ _____

_____ VHS cassettes @ \$25.00.....\$ _____

_____ package(s) Report & Tape @\$45.00..\$ _____

TOTAL \$ _____

Name _____ **Title** _____

Mailing Address _____

Please enclose payment or purchase order. Make checks payable to "BSU Foundation-CICS Account." Return this form and payment to:

Dr. Robert Yadon, Acting Director
Applied Research Institute
Center for Information and Communication Sciences
BC 213
Ball State University
Muncie, IN 47306

Applied Research Institute

The Applied Research Institute (ARI) is located within the Center for Information and Communication Sciences at Ball State University. It features separate glass-lined voice, data and video laboratories, each containing state-of-the-art technology, which provide hands-on training in support of courses within the ICS curriculum. The ARI labs are staffed full-time throughout the calendar year by a director, associate director and a labs manager. In addition, senior researchers from the Center's faculty and associated units on campus utilize the labs to conduct applied research on current and future problems within the information and communication sciences arena.

The ARI labs also serve the information and communication sciences industry through sponsored research projects ranging from beta tests of new products, both hardware and software, to more extensive evaluations across product lines. Specialized training programs are on a contract basis, and a week-long Executive Program allows professionals to work with senior ARI staff on a one-to-one basis over a five-day period.

For more information about the Applied Research Institute, sponsored research, or the new Executive Program, contact:

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Applied Research Institute
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